Unpacking the Formative Assessment Processes of Secondary Mathematics Teachers Who Use Wireless Networked Classroom Technology

DISSERTATION

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Abstract

The use of formative assessment can increase student achievement (Black & Wiliam, 1998a). However, some of the challenges of incorporating formative assessment into instruction include the length of time needed to collect, assess and provide feedback to all students and dealing with students' misunderstandings and incorrect answers that are publicly shared with the entire class (Olson et al., 2010). These challenges can be overcome by incorporating the use of Wireless Networked Classroom Technology (WNCT), such as the TI-Nspire™ Navigator™ System, into instruction. This technology provides anonymity of student responses and allows for quick dissemination and retrieval of information (Olson et al., 2010). The use of WNCT has also led to improvements in student achievement in K-12 and college math and science classrooms as teachers more easily and instantaneously collect, manage, and analyze data received from students (Roschelle, Penuel, & Abrahamson, 2004).

In this qualitative case study research, the formative assessment processes of three secondary mathematics teachers who integrated WNCT, specifically the TI-Nspire Navigator System, were studied. The purpose of this study was to provide detailed accounts of the formative assessment processes in each of these classrooms with the technology. This included key strategies of formative assessment present during instruction, the system features used, questions asked, and each teacher's use of real-time

data. Methods used to collect data included a semi-structured initial teacher interview, non-participant classroom observations, semi-structured pre-and post-observation interviews and where applicable, screen capture of the information displayed to students through an LCD project from the teacher's computer during instruction. These methods were analyzed using a conceptual framework that consisted of the formative assessment framework (Black & Wiliam, 2009), Navigator System features used (Texas Instruments, 2014), question types posed by teachers (Boaler & Brodie, 2004), planning continuum (Shavelson et al., 2008) and levels of feedback provided to students (Lee, 2012).

Results indicated that each teacher demonstrated their own unique process of formative assessment during instruction, but all three teachers integrated key strategies two, three, and four of the formative assessment framework into their instruction. Each teacher also utilized difference system features to support their use of the Navigator System as a formative assessment tool that included the *Quick Polls, Screen Capture*, and *Send/Receive Documents*. The primary purpose for using each of these three features was to *gather information* from students regarding their ability to complete computations with regards to the mathematical content being learned for the day. The feedback that teachers provided to students after reviewing the real-time data was also unique to each teacher. There were 19 different categories of feedback observed during instruction that ranged from *evaluative/normative*, *corrective/verification*, to *elaborative/facilitative* feedback. The results of this research were then used to create a theoretical framework of formative assessment using the TI-Nspire Navigator System.

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Chapter 1: Introduction

Student achievement became a national concern with the implementation of No Child Left Behind (NCLB) in 2001. Just prior to this national concern, a synthesis review of research was conducted by Black and Wiliam (1998a). This review included 250 journal articles and book chapters of studies conducted from age five to undergraduate students in a variety of school subjects from different counties. Results from the various studies indicated that the use of formative assessment increased student achievement with effect sizes between 0.4 and 0.7 when the process of formative assessment and feedback were used to modify the teaching and learning of the respective content and then used to meet the needs of students. As a result, formative assessment became a popular research topic with scholars who were interested to know how formative assessment was being implemented in classrooms and its impact on student achievement (e.g., Bell & Cowie, 2001; Black & Wiliam, 1998b; Heritage, 2010; Popham, 2008; Shavelson, Yin, Furtak, Ruiz-Primo & Ayala, 2008; Torrance & Pryor, 1998). Furthermore, teachers gained an interest in this topic because it could help raise their students' achievement levels. However, some of the challenges teachers face when incorporating formative assessment into instruction include the length of time needed to collect, assess, and provide feedback to all students and dealing with students' misunderstandings and incorrect answers that are publicly shared with the entire class (Olson, Slovin, Olson, Brandon, & Yin, 2010). These challenges can be overcome by incorporating the use of technology to solicit responses and feedback from all students who are wirelessly connected to a classroom network system (Roschelle, Penuel, & Abrahamson, 2004). Classroom network systems are commonly referred to as student (audience) response systems, clickers, classroom response systems, connected classroom technology and networked classrooms (Banks, 2006; Fies & Marshall, 2006; Olson et al., 2010; Shirley, Irving, Sanalan, Pape, & Owens, 2011). The TI-Nspire™ Navigator™ System is one example of a classroom network system used by mathematics teachers to formatively assess all students. This technology can be found in mathematics classrooms beginning with Algebra I, which typically occurs as early as seventh grade, but is used primarily at the secondary level.

The TI-Nspire Navigator System includes computer software for the teacher and allows students with the TI-Nspire graphing calculator to connect their calculators to their classroom network by logging into the system. The teacher is able to wirelessly send questions or documents to students to answer and then retrieve their responses. Hence, the calculator doubles as a student response system. This technology provides anonymity of student responses and allows for quick dissemination and retrieval of information (Olson et al., 2010). The use of WNCT has led to improvements in student achievement in K-12 and college math and science classrooms as teachers more easily and instantaneously collect, manage, and analyze data received from students (Roschelle, Penuel, & Abrahamson, 2004). Furthermore, interactions and assessments between teacher and students may occur more quickly and frequently in classrooms where WNCT is used. Teachers can also give small assessment tasks and provide students with immediate feedback.

In this chapter, the following areas will be addressed. First, the background for this study will be presented. Second, the problem statement and guiding questions of this research will be shared. Third, the significance of the study will be explained followed by the methods used. Then limitations and finally definitions will be provided. To begin, the background of the study will be shared.

Background of Study

Technological advancements in society have impacted K-12 education as digital devices are commonly found in today's classrooms (Cuban, Kirkpatrick, & Peck, 2001). Teachers and students must be prepared to teach and learn with technology as well as be able to communicate with one another through technology. Three professional organizations that support the use of technology for the teaching and learning of mathematics include the National Council of Teachers of Mathematics (NCTM), the International Society for Technology in Education (ISTE), and the Partnership for 21st Century Skills (P21). Each organization has established its own set of standards, with a common thread of making sure teachers and students use technology during their K-12 education and that students are prepared to use technology upon completion of their education.

Technological devices such as interactive whiteboards, graphing calculators, computers, and LCD display units are common hardware devices found in K-12 classrooms today (Bretscher, 2014). The emphasis on student achievement as a result of NCLB creates a need for teachers to learn more about what their students know and understand. Teachers can use technological devices to monitor what students currently know, what misconceptions they might have, and what they still need to learn (Wiliam &

Leahy, 2007; Wiliam & Thompson, 2008). Furthermore, technology, such as graphing calculators with a built-in student response system, can help a teacher gather information and feedback from all students, which can then be used to modify instruction to meet the needs of all students (Black & Wiliam, 1998b). It is claimed that what technology affords that was previously not possible is the ability to gather, organize, and display information from all students in a matter of seconds resulting in quick feedback loops between students and teachers (Roschelle, Penuel, & Abrahamson, 2004).

One WNCT system with two components, the TI-Nspire Navigator System and student graphing calculators, can be used by mathematics teachers to gain feedback from all students. The Navigator System comes with teacher software that is installed on a computer and displayed through an LCD projector. The TI-Nspire graphing calculator is a calculator used by the students, who once logged in are connected to the Navigator System. This allows for information to be sent and received between the teacher's computer and the students graphing calculator.

Two large research studies conducted in Algebra I classrooms with TI-Nspire Navigator System technology included Classroom Connectivity in Promoting Mathematics and Science Achievement (Pape et al., 2012) and Formative Assessment in a Networked Classroom (Olson et al, 2010). Results from the Classroom Connectivity in Promoting Mathematics and Science Achievement study included the impact of professional development and the use of connective classroom technology on student achievement (Pape et al., 2012) and logging files that showed differences in technology implementation type and frequency and student participation throughout the year (Sanalan & Irving, 2007). Results from the Formative Assessment in a Networked

Classroom study included teachers' knowledge about formative assessments, teachers' pedagogical content knowledge, and teachers' attitudes towards technology which included confidence, self-efficacy, value and interest (Olson et al., 2010). Additional results reported on changes in teachers' content knowledge (Gilbert, Olson, Olson, Slovin, & Gilbert, 2010), and achievement growth of students on algebraic concepts focused on patterns and relations (Olson et al., 2010). Furthermore, results from the first study indicated that additional research was needed to determine how the use of technology resulted in increased student achievement (Pape et al., 2012). The purpose of my qualitative case study research was to identify how teachers used the TI-Nspire Navigator System during mathematics instruction. Specifically, this research provides baseline data about teachers' implementation of formative assessment in classrooms with TI-Nspire Navigator System technology. Future research can then build on this baseline data to determine which formative assessment processes using the technology leads to gains in student achievement.

Problem Statement

To address existing gaps in the mathematics education research literature, I researched secondary mathematics teachers' implementation of formative assessment while using the TI-Nspire Navigator System. The specific questions that guided this work were:

1. What does the process of formative assessment look like in secondary mathematics classrooms that integrate the TI-Nspire Navigator System into instruction?

2. How do secondary mathematics teachers use the TI-Nspire Navigator System as a formative assessment tool?
3. How do secondary mathematics teachers use the real-time data collected, organized, and displayed by the TI-Nspire Navigator System?

Significance of Research

What lacks from the current literature on formative assessment, feedback and the use of wireless networked classroom technology (WNCT) during mathematics instruction includes the types of questions teachers ask, the system features used, the feedback provided to students, and teachers' real-time decision-making processes. My research differs from prior research because participants were not involved in professional development sessions to assist them in learning how to use technology nor were they involved in professional development that concurrently supported their development of using the technology and learning to use the technology as a formative assessment tool (Beatty & Gerace, 2009; Olson et al., 2010; Shirley et al., 2011). Instead, teachers who had already adopted and used WNCT, specifically the TI-Nspire Navigator System, and student graphing calculators participated. This research determined what the process of formative assessment looked like in secondary mathematics classrooms that integrated the WNCT, the system features used to assess students, and feedback provided to students as a result of having real-time data collected, organized, and displayed by the system. This research is important because it provides baseline data regarding secondary mathematics teachers' formative assessment processes in classrooms that integrate WNCT during instruction. Specifically, it provides insight to different formative assessment processes when using WNCT, highlights system features and questions that were predominately used to assess students, and identifies the types of feedback teachers provided to students as a result of analyzing real-time data. This study also suggests the importance of feedback to move students forward in their learning and understanding of mathematics.

Methods Overview

This study utilized a qualitative, multiple case study research design of three mathematics teachers who used the TI-Nspire Navigator System and graphing calculators during instruction. Data collection methods included an initial teacher interview, audio-recorded classroom observations, and pre- and post-classroom observation interviews. Where applicable, screen capture was used to record the lessons as they appeared to the class through an LCD projector onto a screen or SMART Board during instruction. The development of a conceptual framework consisting of the formative assessment framework (Black & Wiliam, 2009), question types posed by teachers (Boaler & Brodie, 2004), planning continuum (Shavelson et al., 2008) and levels of feedback (Lee, 2012) were used to analyze the entire formative assessment process of secondary mathematics teachers who used technology during instruction. From these results, models of each teacher's implementation of their formative assessment process were developed. Upon completing individual analyses of each teacher, a cross-case analysis was conducted as a means to address the three research questions that guided this work. The methodology will be described in greater detail in Chapter 3.

Limitations

First, results of this research will not be generalizable to all TI-Nspire Navigator users because the sample size was small and may not reflect the practices that all teachers employ when using the WNCT to formatively assess their students. Second, because the specific population of TI-Nspire Navigator users is small, it was difficult to find teachers teaching the same subjects. Hence, the analysis consisted of teachers who used the Navigator System, but taught different subjects of mathematics. This also contributed to the lack of generalizability of the research results.

Definition of Terms

The following list of terms will be used frequently throughout this paper. Although these terms may be familiar to mathematics teachers and educators interested in graphing calculators or wireless networked classroom technology, those who are unfamiliar with the technology may find these definitions helpful to understanding the hardware and software used by teachers during instruction who have adopted the use of technology when teaching mathematics. For readability, Navigator System features will be italicized throughout this work. I begin with a definition of formative assessment that will be used throughout this work, then those specific to the technology and TI-Nspire Navigator System.

Formative Assessment. Black and Wiliam (1998b) define assessments as:

> All those activities undertaken by teachers – and by their students in assessing themselves – that provide information to be used as feedback to modify teaching and learning activities. Such assessment becomes *formative assessment* when the evidence is actually used to adapt the teaching to meet student needs. (p. 140)

This is the definition of formative assessment that will be used throughout this research, including the analysis.

TI-Nspire Navigator System. This system is comprised of several components to create a wireless classroom environment. Hardware components include the TI-Nspire graphing calculators, wireless network adapter and access communication point. The TI-Nspire Navigator Teacher Software is the lone software component.

TI-Nspire Navigator Teacher Software. The Teacher Software is the software that comes with the Navigator System and is installed and runs on a computer. Four features of the teacher software important for formative assessment are *Screen Capture*, *Live Presenter*, *Quick Polls*, and *Documents*. Each feature will be defined in greater detail next.

Screen Capture. This feature allows a teacher to capture or take a picture of one, multiple, or all student calculator screens in which students are logged in. This feature provides one means of simultaneously monitoring the progress of all students as displayed through the calculator screen. Additionally, the names of students can be hidden, which provides anonymity of work and responses. Teachers can manually or automatically capture screens with the option of setting specific time intervals for collection, if they choose.

Live Presenter. Live Presenter can be used for demonstration purposes on the graphing calculator in real-time. This feature projects one calculator screen for all to see. The projected calculator screen can be that of the teacher or any logged in student. An image of the calculator keypad can also be shown, which highlights the keys as they are being pressed by the presenter. These demonstrations can also be recorded with a keypress history and saved for later use.

Quick Polls. This feature provides teachers with an opportunity to send questions to all student graphing calculators that are logged in, receive individual student responses, and review all student results. The quick polls are instantly sent to the calculators of logged in students, who provide and send their response back. The system then collects, organizes, and can display all student responses for the teacher to analyze. Templates of question types are provided for teachers that include multiple choice, open response, equations and expressions, coordinate points and lists, image, and chemistry. This data can also be saved using the teacher software.

Documents. Documents are files that contain text and images and typically include questions, tasks, or space for students to work on the calculator. Each document created by the teacher or student can contain multiple pages and questions. The Navigator System is capable of sending and receiving files to calculators, regardless of being logged in or not. Students who are enrolled in a class in the teacher software will automatically receive any sent document by the teacher regardless of being logged in. Seven options are available for different functional pages which include Calculator, Graphs, Geometry, Lists & Spreadsheets, Data & Statistics, Notes, and Vernier DataQuest app. Documents can also be designed to grade student responses and modified as needed by the teacher. Once the file is retrieved from student calculators, if correct scores have been entered into the teacher software, the system will automatically grade student responses. This information is stored and saved in the teacher software.

TI-Nspire Graphing Calculator. This calculator is currently a third-generation graphing calculator in the TI-Nspire family. Commonly referred to as a handheld, this device differs from other graphing calculators because it provides touchpad navigation, dynamic graphing, and interactive computer features. Reference to student graphing calculators in this work will be with respect to any version of the *TI-Nspire Graphing Calculator*.

Dissertation Outline

In the chapters that follow, Chapter 2 provides a review of the literature with respect to the process of formative assessment, formative feedback, and wireless networked classroom technology. Then, Chapter 3 provides a description of the methodologies of this qualitative case study research design. Chapters 4, 5, and 6 each represent the results of the three secondary mathematics teachers who participated in this study. Chapter 7 is the cross-case analysis and addresses the specific research questions that guided this work. Finally, Chapter 8 includes discussions and implications of this work.

Chapter 2: Literature Review

In this chapter, three areas of literature that informed this research study will be reviewed. First, the literature on formative assessment will be reviewed. This will include similarities and differences about four models of formative assessment in math and science, the continuum of formative assessment, and a framework of formative assessment for which the present study builds upon. Second, formative feedback and levels as an integral part of the formative assessment process to move learning forward will be considered. Third, the review of wireless networked classroom technology (WNCT) will include a description of one specific system studied in this research, the TI-Nspire Navigator System, features for formative assessment use, and benefits as cited in the literature. This chapter concludes with a conceptual framework for exploring features of the WNCT teachers used during the process of formative assessment and the feedback they provided to students in mathematics classrooms. This review begins with the formative assessment literature.

Formative Assessment

Formative assessments that are an integral part of instruction help guide and inform the instructional decisions made by teachers (NCTM, 2000). Assessments should also support and enhance student learning. Formative assessment has several definitions (e.g., Bell & Cowie, 2001; Bennett 2011; Black & Wiliam, 1998b; Heritage, 2010; Popham, 2008; Shavelson et al., 2008; Torrance & Pryor, 1998). As a result of these differences, models that describe the formative assessment process also differ. However, there are several underlying characteristics that are similar to the models developed by Black, Harrison, Lee, Marshall, and Wiliam (2004), Cowie and Bell (1999), Heritage (2010), and Torrance and Pryor (1998). These frameworks were selected because they were prominently cited in mathematics and science education or written for practitioners. The formative assessment process is described next, followed by similarities and differences of each model.

The Formative Assessment Process

Several models of formative assessment have been suggested in the mathematics and science literature (e.g., Bell & Cowie, 2001; Black & Wiliam, 1998b; Heritage, 2010; Torrance & Pryor, 1998). Each of the models provides a cycle for formative assessment that has similar characteristics. In each cycle, a task, activity, or question is posed to the students, then the elicitation of evidence occurs, followed by interpretation of that evidence, and then feedback is provided to students. This feedback can be from the teacher to student, between students, or through self-assessments by students. The cycle continues until the desired learning goals or outcomes have been achieved.

Similarities and Differences

There is no single framework of formative assessment. However, the four frameworks by Bell and Cowie (2001), Black et al. (2004), Heritage (2010), and Torrance and Pryor (1998) have underlying structures that are common to each other. For instance, each contains some aspect of eliciting evidence of student learning, interpreting that evidence, and then providing students to feedback. The fourth similarity is that each framework allows for assessments from the teacher to students, between small groups of students, or by the self. Self-assessment and self-regulation are also seen as critical components of formative assessment because they help the learner to regulate their learning and understanding as a way to improve.

The underlying drivers of the four frameworks help to distinguish them from one another. The drivers are learning goals or success criteria used by the teacher and students to compare actual levels of learning to the predetermined goals (Heritage, 2010). The three types of drivers that emerged from the research of the four groups of scholars were formative assessment rooted in behaviorism or social constructivism, teacher knowledge, and learning progressions (Black et al., 2004; Cowie & Bell, 1999; Heritage, 2010; Torrance & Pryor, 1998, 2001). The drivers of each framework will be described in more detail below.

Although not explicitly stated, the formative assessment model of Black et al. (2004) was situated within a social constructivist perspective, as teachers were encouraged and supported as they created innovative classroom practices and questioning techniques that would provide students with an opportunity to share their thinking with others. The underlying driver of the Black et al. (2004) formative assessment model is social constructivism. A second driver for this model is teacher knowledge as the teacher is responsible for determining the learning goals of the session and success criteria that students need to meet. How the teachers position themselves on the behaviorist to social constructivist continuum will greatly impact the classroom practices and questions used.

The formative assessment model developed by Cowie and Bell (1999) is rooted in teacher knowledge. As stated previously, this model was developed as a result of their research through determining teachers' views of assessment, classroom observations, and professional development where teachers had an opportunity to reflect on the proposed model of formative assessment. In this model, the teacher is responsible for creating a task or activity that will allow them to formatively assess their students. Hence, the teacher's knowledge will influence the task or activity that is created.

Learning progressions are the driving force in the Heritage (2010) model. These progressions help to identify the big picture of student learning and use a pathway driven by learning goals and success criteria. These goals and criteria are then used with the formative assessment to help determine students' current level of understanding in relationship to the established goals. The progressions also help a teacher determine the current learning status of their students by identifying what is to be learned, where students are compared to the goals, and what students need to accomplish to meet the learning goals and success criteria.

Torrance and Pryor (1998) take a social constructivist approach to formative assessment as the zone of proximal development (ZPD) and scaffolding may be used as part of the formative assessment process (Vygotsky, 1978). However, as a result of their work with teachers, they observed that both behaviorist and social constructivist approaches were used to formatively assess and provide feedback to students. These included convergent and divergent formative assessments. Convergent formative assessment aligned with a behaviorist view of learning in which the teacher was more concerned with determining if a student knew, understood, or could do a predetermined task whereas divergent formative assessment focused on what the student understood about a particular task. Convergent assessments were guided by the curriculum and used to check for student understanding by recalling knowledge or answering questions with a specific answer in mind. These questions or tasks typically followed the traditional Initiation-Reply-Evaluation/Feedback (IRE/F) sequence (Mehan, 1979). On the other hand, divergent assessments were open-ended and guided by what the student understood with respect to the curriculum or concept (Torrance & Pryor, 1998). In sum, the Torrance and Pryor (1998) model for formative assessment was driven by behaviorism and social constructivism, dictated by the teaching strategies employed by the classroom teacher. Next, formative assessment along a continuum will be considered.

The Formative Assessment Continuum

If we consider a continuum of unplanned to planned assessments, we can identify three types of formative assessment that include *on-the-fly*, *planned-for-interaction*, and *embedded-in-the-curriculum* (Shavelson et al., 2008). *On-the-fly* assessments are informal, unplanned, and happen in the moment. The teacher takes advantage of an unexpected instance presented by a student or group of students during instruction to further explore. Although these assessments are unplanned, they flow seamlessly with instruction as the teacher capitalizes on them to help students reach the learning goals and objectives. However, these types of assessments are not natural for all teachers, and thus they may not always occur in every classroom. Those teachers who are willing to use *on-the-fly* assessments are able to capture the essence of a teachable moment and use it to their advantage to meet the student where they are and help to move them forward in their learning.

While creating lesson plans or preparing for instruction, teachers may create *planned-for-interaction* assessments to occur at specific locations of the lesson. These pre-planned, deliberate assessments help teachers collect information to determine where students are in their learning and what gaps in their understanding exist so changes to instruction can be made to meet student needs. These questions are the original ideas of the teacher and created by the teacher. Teachers craft pointed questions that will allow them to gather current student understanding as a way to determine what students currently know versus what they hope students will learn during the lesson. Teachers can then determine changes to instruction that may need to be made on the spot or in subsequent lessons to close the gap between where students are and where they need to be. These central questions can be asked at specific times during the lesson. Although not all students may provide responses, the general evidence that the teacher collects will allow them to make informed decisions about instruction (Shavelson et al., 2008).

The third type of assessment, *embedded-in-the-curriculum*, is included in curriculum materials or pulled directly from the textbook. Similar to *planned-for-interaction assessments,* these assessments are prepared and ready to use prior to the start of a lesson and are also given at critical points during the lesson to ensure that students have learned the necessary information to be able to move on to the next idea. As with *on-the-fly* and *planned-for-interaction* assessments, *embedded-in-the-curriculum* assessments help teachers collect information to determine where students are in their learning and what gaps in their understanding exist so changes to instruction can be made to meet student needs. These assessments differ from the other two because they are part of the existing curriculum and included in the textbook or supplemental teaching materials. These ready-to-give assessments also include a timeline indicating when during instruction the assessment should be given. This continuum will be used to categorize the different formative assessment questions used by teachers in this research. Next, the framework of formative assessment that grounded this research will be shared.

Framework of Formative Assessment

Black and Wiliam (2009) present a framework of formative assessment guided by three main processes based on the work of Ramaprasad (1983) and later Wiliam and Thompson (2008) which include "establishing where the learners are in their learning, establishing where they are going, and establishing what needs to be done to get them there" (p. 63). The five key strategies that help to conceptualize formative assessment include:

1. Clarifying and sharing learning intentions and criteria for success,
2. Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding,
3. Providing feedback that moves learners forward,
4. Activating students as instructional resources for one another, and
5. Activating students as the owners of their own learning" (Black & Wiliam, 2009, p. 8).

Figure 1 below shows the conceptualization of formative assessment in relationship to the teacher, peer, and learner.

	Where the learner is going	Where the learner is right now	How to get there
Teacher	1. Clarifying learning intentions and criteria for success	2. Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding and learning	3. Providing feedback that moves learners forward
Peer	Understanding and sharing learning intentions and criteria for success	4. Activating students as instructional resources for one another	
Learner	Understanding and sharing learning intentions and criteria for success	5. Activating students as the owners of their own learning	

Figure 1. Framework of Formative Assessment (Black & Wiliam, 2009).

Building on their prior work Black et al. (2004) and Wiliam (2007) identified five key strategies of formative assessment that would support student learning if implemented properly. First, Wiliam (2007) generalized the questions category to include observations, activities, tasks and discussions so that a teacher could elicit evidence of student learning. Second, feedback could be written or verbal, as long as it moved learning forward. Third, peer and self-assessment was split into two distinct categories known as activating students as owners of their own learning and as learning resources for one another. Finally, a new area in which students should be made aware of the learning goals and success criteria emerged. Each of the five strategies will be explained in more detail below.

The first strategy of formative assessment is for the teacher to share with students the learning goals and criteria for success for a given lesson. This includes informing students about what they will learn during the lesson and the criteria used to evaluate student work, such as a rubric. One way to help students understand the success criteria is to provide them with examples of previous student work and let them determine the level of quality of the work for each example. From this, students can refer to these examples which indicate exemplary and non-exemplary work (Wiliam, 2007, 2008).

When eliciting evidence of student learning, time and thought must go into the types of discussions, questions, activities, and tasks to use with students to allow for their thinking to emerge and to provide them with the opportunity to share what they know, do not know, or what misconceptions they may have. Carefully crafted questions may contain reasonable, but not mathematically correct answers that help a teacher determine what misconceptions, if any, students have with respect to the current topic. If the teacher is well versed, they will be able to use the responses from students to have a class discussion based on the results, giving students the opportunity to share out and explain their choice. By using instructional time to have these discussions, a larger number of conversations may occur and a greater number of students may have their understanding impacted by participating and listening to the discussion (Wiliam, 2007, 2008).

Feedback is one option that can be used to move learning forward. However, when using feedback it is important to know that the impact can be positive or negative, depending on the type of feedback given (Black & Wiliam, 1998a). For example, if a student receives feedback that is evaluative in nature, such as grades, then the outcome on performance may be negative if the student did not perceive the grade as high enough. If the student repeatedly receives poor grades, they may become discouraged with themselves and their ability to do well in school and shut down (Black & Wiliam, 1998b). Feedback that helps a student understand the quality of their work and how they can improve will positively support students in their learning. Monitoring, diagnostic, and formative assessment are three phases of assessment that can support positive feedback to students. When monitoring, the acknowledgement of a problem emerges. Then, the diagnosis can be used to pinpoint the location of the problem. Finally, the formative assessment provides insight to why the problem is occurring while offering suggestions on how to fix the problem (Black & Wiliam, 1998b; Wiliam, 2008).

A fourth key strategy of the formative assessment framework is to help students take ownership of their learning. Students need to be made aware that the activities of the classroom are created so that students have the opportunity to grow and use these opportunities to take advantage of this growth, instead of shying away from it in fear of failing at the task. Furthermore, teachers need to help students understand that their ability to learn is incremental, not fixed. By doing this, students may view learning as an opportunity to grow instead of a place to potentially fail. Ultimately, students who successfully take ownership of their learning have acquired the skills necessary to self-assess or self-regulate their learning (Wiliam, 2007, 2008).

Finally, students should learn to work with their peers and be learning resources for one another. When students are asked to collaborate, positive results in learning will occur if each member of the group works together to accomplish the given task and each member is held accountable to contribute to the final group product (Slavin, Hurley, & Chamberlain, 2003). Peers may also provide feedback to one another to improve their work. Since feedback comes from another peer, it may be more positively received then coming from the teacher or other adult authority figure. The giver of feedback must listen to the information presented by their peer, internalize it, and then provide an adequate response to support another individual. The comment is not their own so it is easier for the student to provide the feedback. One suggestion to encourage peer feedback is called two stars and one wish. A peer is asked to give two positive comments of the work of their peer, and one comment in an area that may need additional attention or work. Strategies such as the one above will help students learn how to become resources for one another (Wiliam, 2008). When implemented appropriately, these five strategies will aid student learning.

The work by Black et al. (2004) and Wiliam (2007, 2008) that was refined by Black and Wiliam (2009) offered a framework for formative assessment that would cause teachers to adapt their teaching to fit the needs of their students (Black & Wiliam, 1998b). For assessment to be formative, the teacher has to do something with the information collected from the students about their understanding to move the students' learning forward. This allows for a dialogue between teacher and students to occur through the use of feedback that will help students identify what may need attention and how they can improve. This framework also supports an active learning environment in which students collaborate on tasks or questions. Since formative feedback is also a critical aspect of the formative assessment framework, I will consider the literature on this area next.

Formative Feedback

A contributing factor to move learning forward during the process of formative assessment is the use of feedback. More specifically, formative feedback is used to increase learning and skill by communicating to students what modifications to their thinking or behavior need to improve (Shute, 2008). In this section the functions of feedback as identified by Black and Wiliam (1998a), the different feedback conditions described by Hanna (1976), and a description of effective feedback as identified by Kulhavy and Stock (1989) will be discussed. The levels of feedback as described by Lee (2012) will also be shared. To begin, I consider the functions of feedback as described by Black and Wiliam (1998a).

Black and Wiliam (1998a) conducted a synthesis review of research covering 250 journal articles and book chapters on formative assessment studies that included research on students age five to undergraduates in a variety of school subjects. Results indicated that when information received from students during the process of formative assessment was used to alter the teaching and learning of the content, student achievement increased between 0.4 and 0.7 effect sizes. Feedback is one important part of the formative assessment process. As a result of their review of research, Black and Wiliam (1998a) identified the functions of feedback to be *directive* and *facilitative*. The former is specific feedback provided to students indicating what is incorrect or needs to be fixed. The latter is used to guide students to identify what they need to correct through questioning, instead of telling them explicitly what needs to be fixed. In addition to the function of feedback, the amount of feedback provided to students can vary. Different forms of feedback will be described next.

Three forms of feedback, *total*, *partial*, and *none* were used with one multiple choice and two short answer pre and posttests with a mix of 18 questions on science, arithmetic, and social studies data interpretation content administered to 1391 fifth and sixth grade students in six Kansas school districts (Hanna, 1976). In this experiment, the author hypothesized that some form of feedback, either *total* or *partial*, would result in greater performance on the posttest then no feedback. Students were divided into three groups and administered the *total*, *partial* or *no* feedback test. Differences in directions accounted for the type of feedback provided to students. In the *total* feedback test, students revealed letters under a carbon shield until they uncovered an H, which indicated a correct answer. All other letters indicated an incorrect answer. However, students were encouraged to erase as few squares as possible. For *partial* feedback, students were only allowed to erase one square but knew that H was a correct response and all other letters were incorrect. Finally, students who took the *no* feedback test were asked to choose the best answer and fill in the appropriate circle on their answer sheet. Results indicated that students who received *no* feedback performed significantly lower on the posttest than the *total* and *partial* feedback groups (Hanna, 1976). The amount of feedback provided to students can impact their performance.

Kulhavy and Stock (1989) identified two important components to feedback that included *verification* and *elaboration* as a result of reviewing more than 50 studies of experiments completed during the 1970s and 1980s. Of these 50 plus studies, *elaboration* was identified as the independent variable and classified as task specific, instruction-based and extra-instructional. *Verification* was used to inform a student whether their answer was right or wrong whereas *elaboration* might include a corrective statement or provide guidance that leads students to identify why their answer was incorrect. Furthermore, item repetition or a worked example might be used to help elaborate on the error (Kulhavy & Stock, 1989). The categories suggested here were similar in function to those suggested by Black and Wiliam (1998a). It should be noted that the feedback that occurs during the formative assessment process can have different functions and can vary in amount, both of which may affect student achievement and learning during instruction.

The research work of Lee (2012) was part of a larger research study, the Classroom Connectivity in Promoting Mathematics and Science Achievement (CCMS) project. This longitudinal randomized control trial began with 127 Algebra I teachers from 28 U.S. states and 2 Canadian provinces with a range of student sample sizes that ranged between a low of 532 to 696 students over the three years of the project. Lee (2012) created a Classroom Discourse Analytical Tool (CDAT) from qualitative data that included videotaped classroom observations of five physical science teachers who were in their first year of the project. The purpose of this tool was to assess classroom discourse in classrooms as it related to scientific reasoning. One component of this tool was teacher feedback. Lee summarized the feedback literature to create a table that identified levels of feedback based on their features which included the main aspects, focus, feedback content type, ways to deliver, and effect on student learning, shown in Table 1 below.

Table 1. Levels of Feedback (Lee, 2012)

Level	Main Aspect	Focus	Feedback Content Type	Ways of Delivering	Effects on Students Learning
1	Evaluative/ Normative	Self	Grade, Praise, Evaluation, Comparison with others	General comments, No reason, attention to “self”, too long, vague, difficult, or interruptive students’ prompts	No effect
2	Corrective/ Verification	Task	Correction, Right answer, Direct hint, Try again	Short, clear, fast in written and spoken	Sometimes effective
3	Elaborative/ Facilitative	Task	Location of mistakes, Addressing information, Hint/Cue for the direction, Specific error or misconception (what and why)	No correct answers, manageable units for students, considering students’ level, specific and clear, goal orientation, flexible time management	Effective almost always

There are three levels of feedback that include *evaluative/normative*, *corrective/verification*, and *elaborative/facilitative*. Level one feedback had no effect on student learning whereas level two was sometimes effective and level three was almost always effective. The information from this summary is used in my research to identify the level of feedback that each teacher provided to their students after they received and analyzed real-time data from the TI-Nspire Navigator System. Next, the literature on wireless networked classroom technology is presented.

Wireless Networked Classroom Technology

The use of formative assessment can increase student achievement (Black & Wiliam, 1998a). However, some of the challenges of incorporating formative assessment into instruction include the length of time needed to collect, assess and provide feedback to all students and dealing with students' misunderstandings and incorrect answers that are publicly shared with the entire class (Olson et al., 2010). These challenges can be overcome by incorporating WNCT, such as the TI-Nspire™ Navigator™ System, into instruction. This technology provides anonymity of student responses and allows for quick dissemination and retrieval of information (Olson et al., 2010). The use of WNCT has also led to improvements in student achievement in K-12 and college math and science classrooms as teachers more easily and instantaneously collect, manage, and analyze data received from students (Roschelle, Penuel, & Abrahamson, 2004). Interactions and assessments between teacher and students may also occur more quickly and frequently in a connected classroom. With technology, teachers no longer have to count students' votes on questions and can provide rapid cycles of feedback to a greater number of students in real-time (Olson et al., 2010). Next, the history of response systems will be explored as well as a description of the third-generation Navigator System specific to this research.

Soliciting responses and feedback from students using electronic response systems has been in place in large lecture halls since the early 1960s (Judson & Sawada, 2002). Today, these systems are more commonly known as audience response systems, student response systems, or clickers (Banks, 2006). Names aside, these systems provide teachers with opportunities to formatively assess students during instruction. Questions are displayed for the entire class to see, or sent to the device, and students can anonymously submit their answer. Additionally, responses are automatically aggregated and results are instantaneously displayed for all to see. The teacher has the ability to keep track of individual student responses through the supporting system software, but this does require some initial set-up work on their part prior to the beginning of the school year or term. Moreover, student names can be hidden from the class, keeping student identities anonymous (Banks, 2006). This feature provides students with an opportunity to share their thinking and provide answers to questions without the fear of being wrong or publicly humiliated.

TI-Nspire Navigator System

The TI-Nspire Navigator System, or Navigator System, is one type of WNCT that can be used by mathematics teachers to formatively assess all students during instruction. This system can be found in mathematics classrooms beginning with Algebra I, which typically occurs as early as seventh grade, but is used primarily at the secondary level. The Navigator System includes teacher software and a wireless communication system that allows students to use graphing calculators to communicate with the teacher software using radio frequency identification (RFID). An attachment goes onto the top of each graphing calculator and once students log into the system, their calculator screen is projected for everyone to see. Teachers use an LCD projector to display the calculator screen images onto a SMART Board or other flat surface such as a whiteboard or screen for all to see.

Dougherty, Akana, Cho, Fernandez, and Song (2005) conducted an experiment with two eighth-grade Algebra I classes of 25 and 26 students with the treatment group using TI-Nspire Navigator System with graphing calculators whereas the control group only used the same TI-84 Plus Silver Edition graphing calculators. Pre and posttests were used to assess student understanding of Algebra I concepts. Results of this study revealed that because of the ability to project the screens of each student's calculator for all to see while retaining the anonymity of student names resulted in increased student engagement, interaction, and discussion. Next, the different question types that teachers can use to formatively assess their students using the Navigator System will be considered.

There are six question types built into the teacher software that can be used for assessment purposes. These include multiple choice, open response, equations and expressions, coordinate points and lists, image, and chemistry. Furthermore, multiple choice questions that are pre-made include custom options that include ABCD, True/False, Yes/No, Always/Sometimes/Never, Agree/Disagree, or Strongly agree to strongly disagree. Open response questions include an explanation this is not automatically graded or a text match that can be automatically graded. Equations and expressions include those in equation notation or y =, function notation or f(x) = , or expression. Coordinate points and lists allow for a numerical input of (x,y), drop point(s), or list(s). Finally, images can include a label or point on. The label option allows students to fill in the blanks for specific items on the given image. Figure 2 below is an example of a question that includes an image for sigma notation and labels for students to input the index and formula.

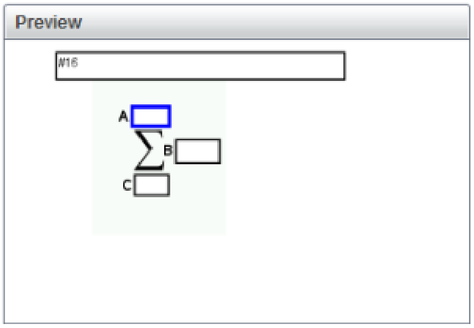


Figure 2. Example of an image question with labels.

The point on option allows the user to check a box indicting their response to a given question that involves an image. One such example might be to ask students to identify the maximum of a given function and is represented in Figure 3 below.

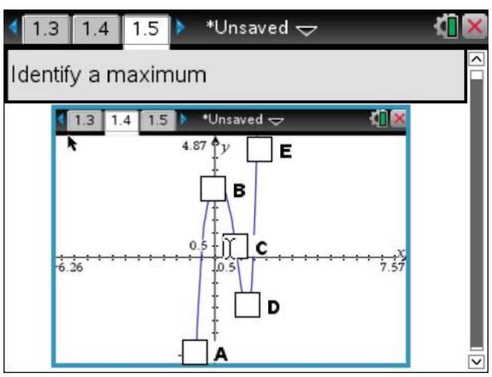


Figure 3. Example of an image question with point on.

There are no additional options available for chemistry questions (Texas Instruments, 2014). These questions provide the teacher with a template that can be modified to fit the needs of their particular question, or left blank for teachers to give a verbal directive to students during instruction. Since students are using a graphing calculator, anything normally done with the graphing calculator can still be done, just with the addition that all screens are displayed for the entire class to see. When responding to questions from *Quick Polls*, one form of assessment, students can use the keypad and functions of the calculator to type in alpha, numeric, symbolic, and graphic responses. The *Screen Capture* feature allows a teacher to highlight interesting work from a student *on-the-fly*, which could then be used to guide instruction.

Four Features for Formative Assessment

There are four features of the Navigator System that teachers can use to formatively assess students. These include the *Screen Capture*, *Live Presenter*, *Quick Polls*, and *Send/Receive Documents*. Each of the four features will be described next.

Screen Capture. This feature allows a teacher to capture or take a picture of one, multiple, or all student calculator screens in which students are logged in, an active page in a document, or images. This feature provides one means of simultaneously monitoring the progress of all students as displayed through the calculator screen. Additionally, the names of students can be hidden, which provides anonymity of work and responses. Teachers can manually or automatically capture screens and at specified time intervals, if they choose.

Live Presenter. The *Live Presenter* feature can be used for demonstration purposes on the graphing calculator in real-time. This feature projects one calculator screen for all to see. The projected calculator screen can be that of the teacher or any logged in student. An image of the calculator keypad can also be shown, which highlights the keys as they are being pressed by the presenter. These demonstrations can also be recorded with a keypress history and saved for later use.

Quick Polls. This feature provides teachers with an opportunity to send questions to students, receive their responses, and review their responses. The *Quick Polls* are instantly sent to the calculators of logged in students, who provide and send their response back. The system then collects, organizes, and displays all student responses. This information can be analyzed by the teacher, or reviewed by students to self-assess. Templates of question types are provided for teachers that include multiple choice, open response, equations and expressions, coordinate points and lists, image, and chemistry. The data can also be saved.

Send/Receive Documents. Documents are files that contain text and images and typically include questions, tasks, or space for students to work through. Each document created by the teacher or student can contain multiple pages and questions. The Navigator System is capable of sending and receiving files to calculators, regardless of being logged in or not. Students who are enrolled in a class in the teacher software will automatically receive any sent document by the teacher regardless of being logged in. Seven options are available for different functional pages. These include Calculator, Graphs, Geometry, Lists & Spreadsheets, Data & Statistics, Notes, and Vernier DataQuest application. These four system features will be referred to when discussing each teacher's formative assessment process in Chapters 4, 5 and 6.

Benefits of Using the Navigator System

One benefit of using the Navigator System is the anonymous public display of responses by students that can be shared with the entire class (Dougherty & Hobbs, 2007). The ability to keep responses anonymous can result in increased student engagement. Dougherty and Hobbs (2007) conducted a quasi-experimental study with

363 students at two sites to determine student achievement and attitudes in Algebra II when students used only the graphing calculator (control) or the graphing calculator with a Navigator System (experiment). Pre- and post-assessments included a survey and content test with items on functions, graphing, solving systems of equations, and concepts of variable. Results indicated that students in the Navigator System environment showed significant gains in content, would self-assess their answer or strategy, identify personal discrepancies and attempt to alleviate them as a result of the public display of responses by all students as afforded by the technology. The public display of responses also allowed students to compare their results to the entire class, not just the people they were sitting by. Furthermore, students in the experimental group were more likely to work in pairs or small groups and interact in lessons that promoted communication and collaboration because teachers in the experimental group tended to use student-centered approaches to learning during instruction (Dougherty & Hobbs, 2007).

A review of research in K-12 and college math and science classrooms conducted by Roschelle et al. (2004) identified 26 studies on classroom networks that reported benefits to using the technology which included “greater student engagement, increased student understanding of complex subject matter, increased student interest and enjoyment, heightened discussion and interactivity, increased student awareness of individual levels of comprehension, and increased teacher insight into student difficulties” (p. 52). One additional major benefit to using WNCT is the ability to collect, manage and analyze data in real-time, thus supporting quick cycles of formative assessment (Roschelle et al., 2004). This is important because it helps a teacher overcome the basic challenges of implementing formative assessment practices into their daily instructional means. Furthermore, interactions between teacher and students or between students are quicker and shorter than in a non-networked classroom. The technology quickly collects and organizes student responses and then displays the results in a matter of seconds. Having this immediate feedback can help drive instruction and provide an avenue for discussion. The use of the Navigator System also allows for effective formative assessment and rapid cycles of feedback that occur in real-time and can help to improve ongoing activities during instruction (Dougherty et al., 2005; Mackay, Olson, & Slovin, 2006; Olson et al., 2010)

A third benefit is the potential for increased student achievement. Pape et al. (2012) conducted a randomized control trial with complete results from 39 treatment classrooms and 43 control classrooms with a total of 1224 students in Algebra I and physical science. Teachers in the control group received the treatment during the second year of this four-year study. The treatment consisted of five days of professional development during a summer institute to learn about formative assessment, how to use the technology, and how to use the technology to formatively assess students with follow-up at the Teachers Teaching with Technology (T^3) International Conference. Results indicated that students in classrooms with the Navigator System outperformed students in the control group with effect size of 0.30. Additional results indicated that connected classroom technology (CCT) disrupted traditional IRE patterns of discourse (Pape et al, 2012). Next, the conceptual framework that was used to analyze this research is shared.

Development of a Conceptual Framework

This literature review helped to inform the development of a conceptual framework for my research. What currently lacks from the formative assessment, formative feedback, and WNCT literature are the actual processes of formative assessment in classrooms with TI-Nspire Navigator System, the types of questions teachers ask, the system features used, the feedback provided to students, and teachers use of real-time data after eliciting evidence of student understanding during the formative assessment process. The purpose of my research helped address these gaps by providing baseline data regarding the implementation of formative assessment in classrooms with WNCT. The components of the conceptual framework include the formative assessment framework (Black & Wiliam, 2009), Navigator System features used (Texas Instruments, 2014), question types posed by teachers (Boaler & Brodie, 2004), planning continuum (Shavelson et al., 2008) and levels of feedback (Lee, 2012) and is represented in Figure 4 below.

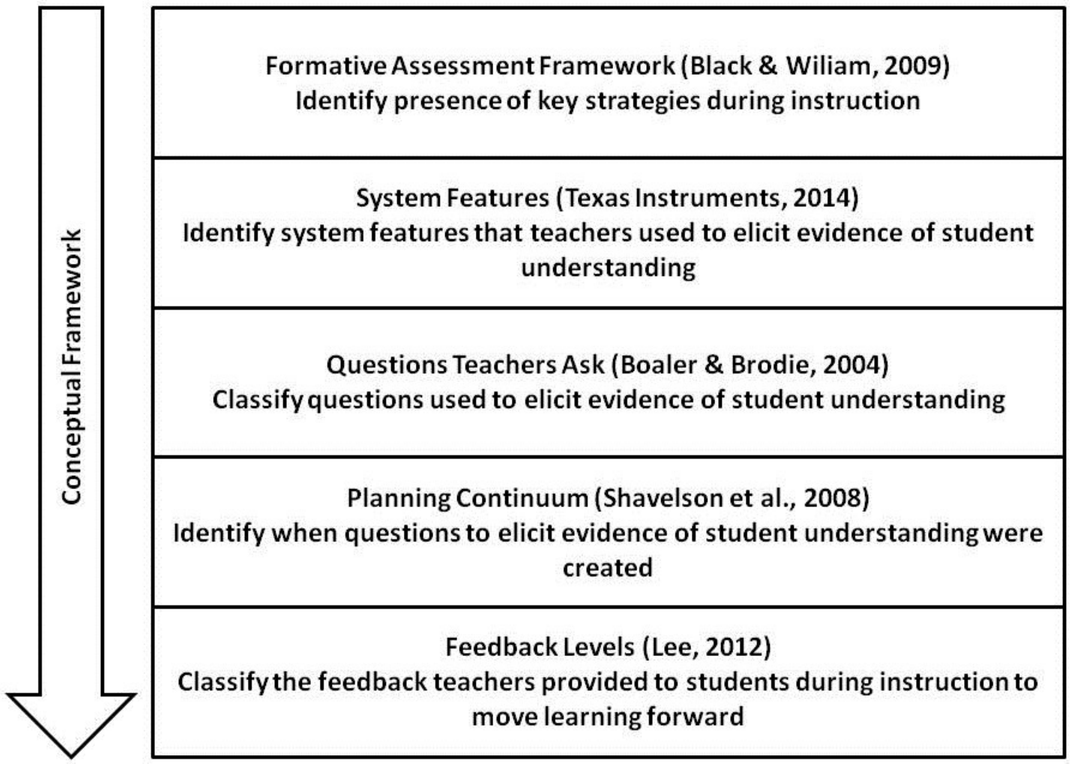


Figure 4. Conceptual framework for analyzing the process of formative assessment while integrating TI-Nspire Navigator System into instruction.

First, the implementation of formative assessment in classrooms that integrated TI-Nspire Navigator System during instruction was considered. This included identifying which of the five key strategies were present during the use of the Navigator System within the process of formative assessment. Hence, the formative assessment process as suggested by Black and Wiliam (2009) was used to identify the key strategies present during instruction. Then, the system features used by teachers was considered. Third, questions teachers asked were identified using categories as described by Boaler and Brodie (2004). Fourth, the planning continuum as suggested by Shavelson et al. (2008) which included *on-the-fly*, *planned-for-interaction*, and *embedded-in-the-curriculum* was used to identify when teachers created the formative assessments using the four selected features of the Navigator System. Fifth, the use of real-time data and feedback provided to students was analyzed using Lee's (2012) levels of feedback. Each of these components was analyzed while the TI-Nspire Navigator System was in use as a way to develop a profile of what the process of formative assessment looked like in mathematics classrooms that integrated TI-Nspire Navigator System into instruction. Table 2 below contains the different frameworks that were used to analyze the data of this research study.

Table 2. Conceptual framework for analyzing the process of formative assessment while integrating TI-Nspire Navigator System into instruction

Framework	Author	Purpose
Formative Assessment	Black and Wiliam (2009)	Identification of the five key strategies present during the process of formative assessment when the Navigator System is used
Question Types	Boaler and Brodie (2004) A priori	Constant comparative analysis to determine the categories of questions that teachers pose using the Navigator System
System Features Used	Texas Instruments (2014)	Quick Poll, Live Presenter, Screen Capture, Send/Receive Documents
Planning Continuum	Shavelson et al. (2008)	To determine when assessments are created in relationship to the lesson
Use of real-time data	A priori	Identify teacher actions/decisions upon receiving real-time data during instruction
	Lee (2012)	To determine each a priori feedback level provided to students

Summary

The literature on formative assessment has helped identify a framework for formative assessment that can be used to trace each phase of the process as it occurs in a mathematics classroom in which WNCT is used (Black & Wiliam, 2009). Second, the use of formative feedback as one means to move learning forward during instruction was summarized into levels that could be used to identify feedback provided to students (Lee, 2012). Third, there are several benefits for using technology that allows students and teachers to connect wirelessly to a classroom network. Benefits cited in this review included increased student achievement, the anonymous public display of student responses, greater student engagement, increased discussion and interactivity, increased self-assessments, increased insight into student thinking, and rapid collection, organization, and display of student responses for formative assessment and feedback purposes in real-time (Dougherty & Hobbs, 2007; Pape et al., 2012; Roschelle et al., 2004). This research will add to this existing literature by providing an in-depth analysis of the process of formative assessment in classrooms that integrate TI-Nspire Navigator System into instruction. This includes the types of questions teachers ask, the system features used, and how teachers respond to the real-time data collected, organized, and displayed by the system. Next, the methodologies used to complete this research will be shared in Chapter 3.

Chapter 3: Methodology

In this qualitative case study research, the formative assessment process of three secondary mathematics teachers who integrated wireless networked classroom technology (WNCT), specifically the TI-Nspire Navigator System, will be studied. The results of this study will provide a detailed account of teachers' formative assessment processes in classrooms with TI-Nspire Navigator System. This includes key strategies of formative assessment present during instruction, the system features used, questions asked, and each teacher's use of real-time data. In this chapter the methodology used to conduct this study will be described. First, an overview of the research design will be given. Then the context of the study and selection of participants will be shared. Third, the role of the researcher will be presented. Then, data collection and methods used during the study will be provided. Fifth, the data analysis will be discussed. Finally, the establishment of trustworthiness for this research will be presented.

The Research Design

This qualitative case study research design included three secondary mathematics teachers who used the TI-Nspire Navigator System during instruction. The purpose of this study was to provide detailed cases for each teacher regarding their process of formative assessment using the technology. Methods included an initial teacher interview (Appendix A), classroom observations (Appendix B), and pre- and post-classroom observation interviews (Appendix C and D). All interviews and observations were audio-recorded. Where applicable, screen capture was used to record the computer screen that was displayed through an LCD projector onto a screen or SMART Board during instruction to capture the WNCT use for each lesson observed. Additional descriptions for each method are provided below. Next, a context of the research study is presented.

Context

The three secondary mathematics teachers who participated in this qualitative case study were all located within the same Midwestern state. However, all three teachers worked in different school districts. Two male teachers, George and Dan, taught in urban school districts defined as having high student poverty and average student population. The lone female teacher, Zoe, taught in a small town district defined as having low student poverty and small student population. The classifications of school districts were defined by the state department of education. Teaching experience in the classroom ranged from nine to seventeen years. Furthermore, teachers' incorporation of the Navigator System into instruction ranged from five to six years at the time in which this study was conducted.

Participants

Participation was open to any mathematics teacher who used the TI-Nspire Navigator System with their students during instruction. Purposeful sampling based on the criterion that teachers used the Navigator System when teaching mathematics was the most important factor, then, snowball or chain sampling was used to locate potential participants (Patton, 1990). The three ways that I located potential participants included using a technology conference database, attending professional development workshops and conferences specific to the TI-Nspire software in July 2013 and March 2014, and by snowballing, or asking current Navigator System users if they knew of other users of the technology or districts that might be willing to participate in this research. Preference for inclusion was given to those responding teachers and districts that were within close proximity to me for travel purposes. District approval was granted in three districts that met the technology criterion. Upon district approval, potential participants were recruited to participate in this research.

Role of the Researcher

My role during this research study was to observe classroom teachers in action while using the TI-Nspire Navigator System. I chose to use the method of non-participant observation (Denzin & Lincoln, 2011; Liu & Maitlis, 2010) because I did not want to influence teachers' existing practices using the technology nor their processes of formative assessment. Instead, I wanted to have a direct understanding of the teachers' processes of formative assessment when using the technology at it naturally occurred in the classroom (Liu & Maitlis, 2010). Additionally, these teachers received no treatment or intervention with regards to the use of technology or the formative assessment framework. I did conduct pre- and post-observation interviews with teachers that required them to think about the assessments they were giving their students through the Navigator System, how they thought students might perform on those tasks, and the knowledge they drew upon to anticipate how students would respond. As a result of these conversations, teachers were forced to think about their instruction prior to or after class and reflect on their actions. These conversations may have impacted each teacher over the course of the observation period. However, the goal of these interviews was to learn more about how and why each teacher planned to assess their students and then observe the assessment process during instruction. Any change that may have occurred as a result of these conversations was unintentional on my part and was not the focus of this study. I simply wanted to observe teachers in action without any treatment to record what happened in practice on a daily basis when using the TI-Nspire Navigator System with respect to the process of formative assessment.

Data Collection and Methods

The data collection period began in January 2014 and concluded in November 2014. During this time five sets of data collected included an audio-recorded initial teacher interview (Appendix A), audio-recorded pre and post-classroom observation interviews (Appendix C and Appendix D), audio-recorded classroom observations (Appendix B), and when possible, screen capture of the lesson. Screen capture displayed content information and showed the use of the Navigator System as it was projected from the teacher’s computer through an LCD projector onto a SMART Board. The data reported in this study came from 37 hours 51 minutes of audio-recorded classroom observations of the three secondary mathematics teachers. A breakdown of time spent in each classroom is represented in Table 3 below.

Table 3. Breakdown of observation time by teacher

	George	Zoe	Dan	Total
Time (hours, minutes)	12h 4m	11h 54m	13h 53m	37h 51m

The amount of time spent observing allowed for prolonged engagement and persistent observation of each teacher within their classroom environment to become familiar with their teaching styles and the daily use of the Navigator System (Lincoln & Guba, 1985). Together, these provided scope and depth to each secondary mathematics teachers' process of formative assessment within their classrooms when using the TI-Nspire Navigator System. Additional details regarding each method are provided next.

Initial Teacher Interview

Each participant was initially interviewed prior to any classroom observations from 30 to 45 minutes. The purpose of this semi-structured interview was to gain demographic information such as educational background, number of years taught, how long teaching with technology, and how they used technology during instruction. Furthermore, this baseline data provided insight into a teacher's choice for using the Navigator System, the types of questions asked, and how they used the real-time data collected, organized and displayed by the Navigator System.

Observations

Non-participant observations using the observation protocol were conducted over the course of a unit of instruction when possible. The audio-recorded classroom observations occurred from January through November 2014. George's lessons were observed 14 times, Zoe's observed 17 times, and Dan's observed 17 times. The purpose for conducting classroom observations over the course of the unit was to see potential day-to-day formative assessment processes as well as those that occurred over the entire unit of instruction. The observation of classroom instruction allowed for data triangulation to occur with information stated in the initial teacher interview and pre-observation interviews by the teacher. In addition to the audio-recorded classroom observations, the screen that displayed lesson information and the aggregated data from the Navigator System was captured using SMART Notebook software when possible.

Teachers who had a SMART Board in their classroom and already recorded and publically posted their lessons as part of their teaching practices were asked to share their videos. Those teachers with a SMART Board who did not record their lessons were asked to consider recording and sharing that information with me. Teachers who posted videos publically (i.e. they were posted online for anyone to view) were asked to ensure that it was okay to use the already available data for research purposes. These videos were used to triangulate the data and supported the data analysis process.

Interviews

Pre and post-classroom observation interviews were also semi-structured and audio-recorded. The purpose of the pre-observation interview was to gain knowledge regarding the use of the Navigator System, the specific questions to be asked, features used, and teachers' anticipations of students' performance on the questions. The post-observation interview questions were asked to follow-up on any changes to the use of the Navigator System that differed from what was stated in the pre-observation interview or that which occurred during the classroom observation and to discuss student performance on the posed questions. Furthermore, additional questions asked teachers to reflect on the real-time data and discuss what thoughts occurred while they analyzed the data during instruction and how that information prompted their feedback to students. The length of the pre and post-classroom observation interviews varied between a few to twenty-five minutes, depending on the teacher's schedule. It should be noted that some of the post-observation interviews did not happen immediately after a classroom observation because the teacher's schedule would not allow it. However, the post-observation occurred later in the day once the teacher had available time. To minimize the amount of time taken away from a teacher, the pre and post-observations occurred at times most convenient for them.

Data Analysis

The goal of this research was to learn more about secondary mathematics teachers' formative assessment processes in classrooms that integrated wireless networked classroom technology, specifically the TI-Nspire Navigator System, during instruction. This research also provided information about secondary mathematics teachers' use of the Navigator System as a formative assessment tool and the real-time data collected, organized, and displayed by the system. In this section, the frameworks used to analyze the data with respect to the research questions are described.

All audio-recorded classroom observations and interviews were transcribed verbatim. Then MAXQDA 11 software was used to code the classroom observations with respect to the process of formative assessment (Black & Wiliam, 2009), features used (Texas Instruments, 2014), questions asked (Boaler & Brodie, 2004), planning continuum (Shavelson et al., 2008), feedback provided to students and levels of feedback (Lee, 2012). Additional details regarding the analysis are provided below. Each case was coded in its entirety as a means to identify the teacher's process of formative assessment in the classroom, learn about their use of the TI-Nspire Navigator System as a formative assessment tool, and determine their use of the real-time data and feedback provided to students. Upon completing the individual case analysis, the three cases were analyzed together to identify similarities, differences, and patterns in Navigator System use with respect to the process of formative assessment. The conceptual framework represented by Figure 4 in Chapter 2 on page 36 provided insight to the frameworks used to analyze the data. A description for each framework with respect to the analysis follows.

Each teacher's formative assessment process was analyzed using Black and Wiliam's (2009) framework of formative assessment. The five key strategies of the framework include: 1) clarifying and sharing learning intentions and criteria for success, 2) engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning, 3) providing feedback that moves learners forward, 4) activating students as instructional resources for one another, and 5) activating students as the owners of their own learning. The transcriptions were uploaded to MAXQDA 11 and codes of the five key strategies created. The first pass of the data identified each key strategy as it occurred during instruction, specifically when the TI-Nspire Navigator System was in use. The exception was key strategy one because it often occurred at the beginning of instruction and was shared verbally by the teacher with students, not using the technology.

The second pass of the data focused on instances in which the Navigator System was in use to determine the system features selected. The four system features included *Quick Polls*, *Live Presenter*, *Screen Capture*, and *Send/Receive Documents*. Other uses of the system were coded a priori as they emerged and included student log in and attendance. Again, these codes were created in the MAXQDA 11 software. This software was then used to code the features used during Navigator System use during instruction.

On the third pass, the questions that each teacher asked students using the TI-Nspire Navigator System were initially coded using the question types framework by Boaler and Brodie (2004) and is represented in Table 4 below.

Table 4. Teacher Questions Framework (Boaler & Brodie, 2004)

Question Type	Description
1. Gathering information, checking for a method, leading students through a method	Wants direct answer, usually wrong or right Rehearses known facts or procedures Enables students to state facts or procedures
2. Inserting terminology	Once ideas are under discussion, enables correct mathematical language to be used to talk about them
3. Exploring mathematical meanings and relationships	Points to underlying mathematical relationships and meanings Makes links between mathematical ideas
4. Probing; getting students to explain their thinking	Clarifies student thinking Enables students to elaborate their thinking for their own benefit and for the class
5. Generating discussion	Enables other members of class to contribute and comment on ideas under discussion
6. Linking and applying	Points to relationships among mathematical ideas and mathematics and other areas of study or life
7. Extending thinking	Extends the situation under discussion, where similar ideas may be used
8. Orienting and focusing	Helps students focus on key elements or aspects of the situation in order to enable problem solving
9. Establishing context	Talks about issues outside of math in order to enable links to be make with mathematics at later point

The affordances of the technology supported teachers in generating question types beyond those found in the framework above. For example, teachers could ask students to itemize incorrect responses from a quiz or test, a question that is typically not asked of students without technology due to the amount of time needed to gather and enter this information. With technology, this question can be asked because each student quickly records their information and submits to the teacher. Therefore, question types that were asked using the TI-Nspire Navigator System were compared to those in the framework of Boaler and Brodie (2004) using constant comparative analysis (Glaser & Strauss, 1967; Corbin & Strauss, 2008). A priori codes for new categories as a result of the affordability of the Navigator System were created as needed and compared across all questions types as they occurred in the analysis for each teacher and across cases during the cross-case analysis. The reason for using constant comparative analysis to code the questions was because the addition of the technology added a layer of flexibility in question design and use not reflected in the questioning framework of Boaler and Brodie (2004). By using constant comparative analysis, the question types that emerged in the data added to this existing framework. When coding a priori using constant comparative analysis, as new data was gathered, each was analyzed to look for discrepant or negative cases against the exiting codes, categories and themes (Erickson, 1986; Patton, 1990). Modifications to the coding scheme were made as needed and all previous data was reviewed for the new categories (Bowen, 2009).

In addition to coding questions, the continuum from unplanned to planned assessments by Shavelson et al. (2008) was used to determine if the questions were created prior to or during instruction and whether the teacher created the question on their own or if they took questions directly from their curriculum or supplemental resources. Table 5 provides a description of the three question types with regards to the planning continuum. Codes for the planning continuum were created in MAXQDA 11 software, with the analysis occurring on the fourth pass of the data analysis.

Table 5. Description of planning continuum for question types (Shavelson et al., 2008)

Planning continuum question type	Creation time and author	Description
On-the-fly	During instruction by the teacher	In the moment, unplanned, informal assessments. The teacher capitalizes on a teachable moment during instruction.
Planned-for-interaction	Prior to instruction by the teacher	Pre-planned, deliberate assessments crafted by the teacher that occur at specific times during instruction to determine if students are moving towards the learning goals.
Embedded-in-the-curriculum	Prior to instruction and from curriculum or supplemental resources	Assessments that come from the textbook, curriculum, or other supplemental resource that tells the teacher specifically when to give during instruction.

The fifth pass of the data included another round of a priori coding with respect to the use of real-time data and feedback that teachers provided to students after giving an assessment using the Navigator System. After categorizing each teacher's feedback, Lee's (2012) levels of feedback framework provided an assigned level of feedback to the a priori data identified in the fifth pass. The levels of feedback codes were created in the MAXQDA 11 software and came directly from Lee's levels of feedback framework. A description of the levels of feedback was presented in Table 1 and can be found in Chapter 2 on page 26 of this document.

Frequency tables and descriptive statistics were used to identify the most prominent features used, questions asked, and the types and levels of feedback provided to students. These frequency tables were also helpful in identifying similarities, differences and patters across cases.

Trustworthiness

To establish trustworthiness of qualitative research, the work must be credible, transferable, dependable, and confirmable (Lincoln & Guba, 1985). The following is a description of how this research met each of these four criteria. First, five key activities that helped to support the credibility of the data included prolonged engagement, persistent observation, triangulation of the data, negative case analysis, and member checks. The three teachers were observed during classroom instruction over an entire unit when possible. The total amount of time spent observing was 37 hours 51 minutes. This included 14 lessons observations of George, and 17 of both Zoe and Dan. Participants in this qualitative research study were observed until data saturation regarding the use of the Navigator System during the process of formative assessment had occurred in the classroom. Triangulation of the initial teacher interview, pre-observation interview, and classroom observations were used to verify each teacher's use of technology during instruction. Persistent observation also occurred as an entire unit of instruction was observed when possible. Negative or discrepant case analysis coupled with constant comparative analysis occurred when identifying the different question types the teachers asked when using the Navigator System. When a question type went against the patterns already identified in the analysis, a new category was formed to account for the differences. Then all previous data was reviewed for the new category.

An additional method used to enhance the trustworthiness of this research was the use of member checks (Lincoln & Guba, 1985). A summary of each teacher's formative assessment process when the TI-Nspire Navigator System was in use, the system features used, questions asked, feedback, and levels were shared with the participants. All three participants were contacted via email and asked to schedule an in-person conference to review this information. All three teachers responded to the email. However, one of the teachers was unable to meet due to scheduling conflicts. Thus, only two of the three teachers confirmed that they were represented in the data. One was able to meet in person, and a second teacher confirmed via email that they were represented in the data. The likelihood that credible findings were produced increased with the prolonged engagement, persistent observation, triangulation of data, negative case analysis, and use of member checks (Erickson, 1986; Lincoln & Guba, 1985; Patton, 1990).

A thick description of the procedures used, methods, and analysis helped make the research process transparent to the reader (Patton, 1990). Providing this thick description supports the transferability of this research. Dependability and conformability were achieved by keeping a well-documented audit trail (Lincoln & Guba, 1985). The data corpus included field notes, each teacher's real-time data results from the formative assessments used with the Navigator System, a copy of the lesson notes, screen capture of the lesson when possible, lesson plans, handouts provided to students, audio-recorded initial teacher interview, pre- and post-classroom observation interviews, classroom observations and the codebook from the qualitative data analysis. Having the data corpus and audit trail available provide concrete evidence that the research was conducted and thorough analysis occurred.

Summary

This qualitative case study research was conducted with three secondary mathematics teachers who used the TI-Nspire Navigator System during mathematics instruction as a way to determine their process of formative assessment when using the technology. Methods used during this research included an initial teacher interview, audio-recorded classroom observations with screen-capture and corresponding pre- and post-classroom observation interviews. The collection of data began in January 2014 and continued through November 2014. The goal of this research was to be able to identify teachers' formative assessment processes when using Navigator System, system features used, questions asked, and teachers' use of real-time data. In chapters 4, 5, and 6 the results for George, Zoe, and Dan will be shared.

Chapter 4: The Case of George

The next three chapters will report findings of three secondary mathematics teachers, George, Zoe, and Dan, who were regular uses of the TI-Nspire Navigator System. Each chapter will provide a detailed profile for each teacher with regards to their formative assessment process when using the technology in relationship to the research questions that guided this inquiry. A cross-case analysis will follow the three case studies and will be presented in Chapters 7 and 8. Data in the form of audio-recorded pre and post-classroom observation interviews, classroom observations, and screen capture when possible were collected and analyzed to address the following research questions that informed this work:

1. What does the process of formative assessment look like in secondary mathematics classrooms that integrate the TI-Nspire Navigator System into instruction?
2. How do secondary mathematics teachers use the TI-Nspire Navigator System as a formative assessment tool?
3. How do secondary mathematics teachers use the real-time data collected, organized, and displayed by the TI-Nspire Navigator System?

The structure of this chapter and each case study is described as follows. First, a summary of the question type categories that were observed while teachers used the Navigator System will be defined. This includes those categories previously identified by

Boaler and Brodie (2004), but within the context of using the Navigator System and those questions types that emerged in the analysis. Second, I will introduce each teacher and the classes in which the observations occurred. Third, the formative assessment process of each secondary mathematics teacher in relationship to the five key strategies as suggested by Black and Wiliam (2009) will be considered. This includes a mapping of the five key strategies to the classroom observations to identify the key strategies that were present in each of the teachers' classrooms and a trajectory of what the process of formative assessment looked like in each classroom when the technology was used. Fourth, the features of the TI-Nspire Navigator System used by teachers will be described. This includes identifying whether the assessments were *on-the-fly*, *planned-for-interaction*, or *embedded-in-the-curriculum* (Shavelson et al, 2008). Fifth, how teachers used the real-time data collected, organized, and displayed by the system will be shared. This includes an analysis of the feedback using Lee's (2012) levels of feedback framework. Each case study concludes with a summary of each teacher's process of formative assessment when using the Navigator System during instruction, primary system features used and use of real-time data. All identifying information has been replaced with pseudonyms to maintain participant confidentiality. This research will help to address existing gaps in the literature specific to teachers' formative assessment processes in classrooms with TI-Nspire Navigator System as knowledge in this area and that regarding effective classroom assessment is unclear (Wiliam & Thompson, 2008, p. 58). Next, the question type categories that emerged from the classroom observations will be defined.

Question Types Teachers Used with Navigator System

In this section, the seven question types that teachers used to support formative assessment through the Navigator System in their classrooms are shared. These categories included 1) *gathering information, checking for a method, leading students through a method*, 2) *collect scores or points earned on an assignment*, 3) *correct text entry/computation*, 4) *item analysis for quiz or test*, 5) *make a prediction*, 6) *recall of prior knowledge*, and 7) *submit questions from homework*. Each category will be defined next.

The first category of *gathering information, checking for a method, leading students through a method* comes from the teacher question type framework of Boaler and Brodie (2004). This category will be referred to as *gathering information* from this point forward. The following is a description of how teachers in this study *gathered information* during instruction. *Gathering information* was a question used by teachers to check if students could use the information learned during the lesson to correctly compute an answer in the present moment of the current lesson and content being learned that day. It was a quick check to get a feel for whether or not students could use the knowledge learned right now. Additionally, the content being learned was new, not something learned in a previous lesson or course. This included asking questions that had a direct answer or to check if students were right or wrong. Furthermore, these questions allowed student to rehearse or state facts and complete procedures (Boaler & Brodie, 2004).

The *collect scores or points earned on an assignment* question allowed students to report their scores to the teacher through the Navigator System. This *Quick Poll* question contained the range of possible scores earned on the assignment so that students could select their appropriate score and submit the information for the teacher to retain an electronic record.

Correct text entry/computation allowed the teacher to check if students were able to correctly input information into the calculator. The reason for having this type of question was because the TI-Nspire graphing calculator used templates for various symbols and mathematical entities such as fractions. Additionally, parentheses were automatically inserted with certain entities and students had to know which characters to include and exclude when using parenthesis. Hence, this type of question allowed the teacher to check the syntax entered by students to verify their capability to correctly enter information into the calculator for computational purposes.

The *item analysis for quiz or test* question provided students with a list of questions from each assessment. This included a number for each question and any sub-question on the assessment. Students were then asked to go through and select each question or sub-question they missed. This provided the teacher with an electronic record of item analysis for each student, the class as a whole, and could be used with other sections to compare how students did on concepts course wide.

Make a prediction required students to provide a prediction for a given concept. This type of question included predications for concepts students may or may not have encountered prior to their current course. This question gave students an opportunity to share their predictions and gave the teacher an idea of prior student knowledge before covering the content.

Recall of prior knowledge asked students a question regarding content they learned yesterday, the day before, earlier that week, last month, sometime in their current course, or in a course that would be a prerequisite for the current course they were enrolled in. This question differs from *gathering information* because students were not being assessed on material they learned about today; instead they were asked to answer a question based on knowledge acquired prior to today's lesson. Students used prior knowledge to answer a present question.

Submit questions from homework provided students with a list of question numbers from an assignment in which students selected those questions they wanted to cover as a class, had questions about, did not complete, struggled with, etc. This question allowed students to state which questions they struggled with and also helped to focus time spent going over homework on questions of the majority. Table 6 summarizes the seven question types asked of students by the three teachers who participated in this research.

Table 6. Question types teachers asked using the Navigator System

Question Type	Description of category
Gathering information	Used to check if students could use information learned in current lesson to compute an answer, rehearse or state facts, or complete procedures (Boaler & Brodie, 2004)
Collect scores or points earned on an assignment	Students reported scores earned on an assignment by selecting the multiple choice box corresponding to their points earned
Correct text entry/computation	Used to check if students could correctly input information into the calculator
Item analysis for quiz or test	Students selected all questions they missed on an assessment

Continued

Table 6 continued

Make a prediction	Predict result prior to learning
Recall of prior knowledge	Students answered a question about content that was learned prior to the current day's lesson
Submit questions from homework	Students selected all questions from homework they wanted to cover as a class, had questions about, did not complete, struggle with, etc.

In the Navigator Use in the Classroom section of each case study, the question types used by each teacher, with an example, will be provided. It should be noted that these seven categories are a collection of the question types used by the teachers who participated in this research. Only one teacher used all seven categories. The other teachers used question types that fit their assessment needs relative to the courses they taught. Next, the case of George will be considered.

The Case of George

I begin by considering the case of George, a veteran secondary mathematics teacher with 17 years of teaching experience, five of which included the integration of Navigator technology into instruction within his current district. George completed his undergraduate work in education and was licensed to teach students in secondary mathematics in grades 7 through 12. He also completed a Master's degree in school counseling. The district in which George worked was classified by the state department of education as an urban district with high student poverty and average student population. Over time the technology in George's school district evolved. Initially, students at the secondary level used TI-83 and 84 graphing calculators while the teacher used the TI-presenter that could be viewed through the classroom television set to support the teaching and learning of mathematics. Eventually interactive whiteboards, specifically SMART Boards, were installed in classrooms. George had used a SMART Board for the past 12 years. This included using the TI-SmartView software with the SMART Board during instruction. A pilot program with Texas Instruments provided George with a TI-Nspire Navigator System and student graphing calculators for the past five years. During the 2013-2014 school year, the district mandated that all students in grades 9 through 12 and those eighth grade students in Algebra I purchase the TI-Nspire CX graphing calculator. Additionally, all teachers in the high school have a Navigator System in their classroom. George has seen technology evolve in his district during the 15 years that he has been a member of the Mathematics Department. He has been fortunate enough to be able to use the Navigator System for the last five years with his students in courses that include Applied Mathematics, Advanced Mathematics, and AP Calculus. The results reported are from 14 classroom observations of these classes.

Classroom Observations

I had the opportunity to observe George teach 14 lessons. This included 4 lessons in Applied Mathematics, 8 lessons in Advanced Mathematics, and 2 lessons in AP Calculus during the spring of 2014. Class periods were 51 minutes, with the exception of AP Calculus that lasted 56 minutes due to meeting during the lunch hour. This is a common practice to allow for a few additional minutes of instruction in a course in which students test for college credit. All courses taught by George fell within the district's curriculum after Algebra II. The content in Applied Mathematics mirrored that of Advanced Mathematics. However, students enrolled in Advanced Mathematics would enroll in AP Calculus the following year whereas students in Applied Mathematics would not.

During the classroom observations I focused on George's use of the Navigator System to identify his formative assessment process. This included what the formative assessment process looked like in a typical classroom in which the TI-Nspire graphing calculators and Navigator System supported George in assessing his students, the types of questions asked and features of the Navigator System used, and how George used the real-time data. There were 31 instances of the Navigator System in use over the 14 lessons. The results reported here are representative of those 31 instances.

The formative assessment process that George used when implementing the TI-Nspire Navigator System into instruction will be considered first. The five key strategies of a theoretical framework of formative assessment as proposed by Black and Wiliam (2009) were used along with the transcripts from the classroom observations to identify instances of each key strategy while the technology was used during instruction. The analysis helped to inform George's formative assessment process as witnessed during his instruction. Results from the analysis are given next.

Key Strategies of Formative Assessment

Black and Wiliam (2009) provide a framework that included five key strategies for formative assessment. These key strategies include: 1) clarifying and sharing learning intentions and criteria for success, 2) engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning, 3) providing feedback that moves learners forward, 4) activating students as instructional resources for one another, and 5) activating students as the owners of their own learning. This framework was presented in Figure 1 from Chapter 2 and can be found on page 19.

This framework was used to analyze the 14 classroom observations as a means to identify which of the key strategies were present during instruction when the TI-Nspire Navigator System was in use. Key strategies that were present during instruction, but not when the technology was in use are also noted below. Next I will describe the presence of each key strategy during instruction and how George's process of formative assessment when using the Navigator System integrated these key strategies.

George used the Navigator System in all 14 lessons that I observed. In 11 of these lessons he verbally clarified and shared the learning intentions and criteria for success with students at the beginning of class. The learning intentions were referred to as learning targets and provided students with a statement of what mathematical concept or task they should be able to accomplish by the end of class. The learning targets were included in the class notes, but were not shared with students through the Navigator System. An example of a learning target that George shared with his students occurred during a lesson in which students were using Heron's (Hero's) Formula to find the area of a triangle. George stated that, "Here's our learning target. So our goal for today is essentially what this is, you will be able to calculate the exact area of a triangle given the lengths of its 3 sides without a calculator." (Observation 1, 2/13/14). The other learning targets shared with students were of a similar nature.

The second key strategy is engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning. The primary way that George collected evidence of student understanding and learning was to use the

Quick Polls feature of the Navigator System. By utilizing this feature, George could pose example questions to students during the notes portion of the class to *gather information*, ask them to *make a prediction*, *recall prior knowledge*, *gather homework questions*, or collect assessment data from each student. Often times George would begin an example problem with students, ask them to finish from the point in which he stopped, and then gather their answers using a *Quick Poll*. There were additional instances when the class worked through examples together and then towards the end of class, students were given additional problems to try in their groups. Once completed, they would submit their answers via the Navigator System. One example in which students worked through two problems together occurred in the AP Calculus class during the first observation. During this lesson students were just beginning to learn about definite integrals and were using graphs to help them find the area under a curve. The class worked through two examples together and then students were given a third definite integral example to try in their groups. Upon completion, students also submitted their numeric answer to a *Quick Poll* question. Details regarding the *Quick Poll* questions will be discussed in more detail in the Navigator use in the classroom section of this chapter.

The third key strategy of formative assessment is providing feedback that moves learners forward. In this section, an overview of the feedback that George provided to his students is presented. A more in depth description of the feedback provided to students will be shared in the use of real-time data section of this chapter. The feedback that George provided to students occurred after he reviewed *Quick Poll* results and included *re-teaching, explaining, scaffolding*, *confirming a correct answer and moving forward* *with instruction*, or *asking a student to provide a justification*. This feedback tended to be *elaborative/facilitative*, or level three feedback.

Activating students as instructional resources for one another is the fourth key strategy of the formative assessment framework. George paired and grouped students through the seating chart. Students were often encouraged to collaborate when working through examples, check their answers against their group members, or to discuss their homework with each other. During one lesson, George gave students time at the beginning of class to review the previous night's homework with group members, correct as needed, and then was going to poll them for any remaining questions. By giving students time to work together to review the homework, he hoped they would be able to answer some of their own questions in groups. This would help diminish the time the entire class spent going over homework and would potentially reduce the number of questions students had. George planned to give students, "five minutes in your groups to help each other correct either ones from yesterday or today and then I will poll you in a few minutes" (Observation 2, 3/11/14). During another lesson where students used Heron's formula to find the area of a triangle, George encouraged students to work together as they finished example problems by stating, "I strongly encourage you to help one another, collaborate with one another, check your answers with one another and then we will see what you got" (Observation 1, 2/13/14). Students were encouraged to work together on example problems and to check and correct their homework with group members.

The fifth key strategy of the formative assessment framework is activating students as the owners of their own learning. George would often ask questions of the class to get students to reflect on their learning and the concepts that were challenging for them. During the lesson in which students used Heron’s formula to find the area of a triangle, George noticed that students were struggling with the example problem. He asked students, “What’s the biggest issue you are having here?” as a way for them to identify which part of the problem was the biggest challenge for them so he would help them through it (Observation 1, 2/13/14). Later in the same lesson he asked students to identify, “the part that’s going to give us a little trouble is the what?” as a way for students to consider difficult concepts for themselves. During the same lesson George wanted students to understand where the parts of Heron’s formula came from by stating, “Make sure you understand the formula.” (Observation 1, 2/13/14). The previous three statements encouraged students to become owners of their own learning by identifying parts of problems that were personally challenging and promoted reflection on their understanding of content. Although there was evidence of key strategy five, there were only three instances in which this key strategy appeared while the Navigator System was used. Due to the limited number of occurrences of key strategy five, it was not included in George’s formative assessment process.

The process of formative assessment that George typically used during instruction occurred in lessons in which students learned new content or worked through example problems as part of their class notes. This process included the use of the *Quick Polls* feature of the Navigator System and is presented below in Figure 5.

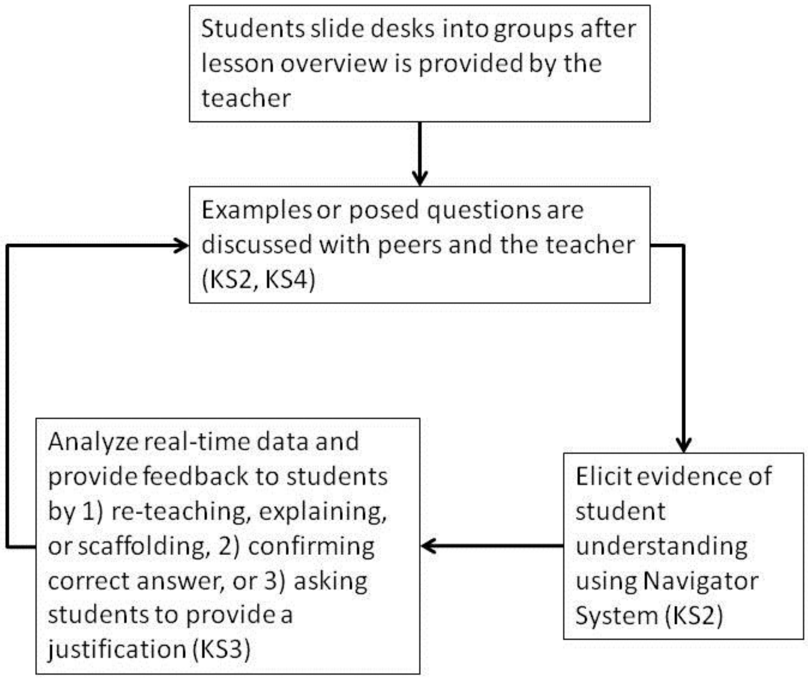


Figure 5. George's typical process of formative assessment.

George's formative assessment process included key strategies two, three, and four. Both key strategies one and five were present during instruction. However, key strategy one was not included because the sharing of learning intentions and criteria for success with students occurred verbally, not through the Navigator System. Key strategy five was also not included in his process of formative assessment because of the limited number of occurrences when the Navigator System was in use.

George's typical formative assessment process consisted of having students move their desks from rows into groups typically after the learning objectives for the day's lesson were shared with students. Second, students worked through examples or posed questions individually, with their group members, or through discussions with the teacher. Third, George would use the Navigator System to ask students questions and elicit evidence of their understanding. Students would then provide feedback to George by answering the question sent to their calculator. The information in a typical class was then collected, organized, and displayed by the Navigator System for all to see the results. George analyzed the real-time data and then provided feedback in one of three forms. Most frequently, George would re-teach, provide the explanation, or scaffold students' thinking by asking guided questions. Other forms of feedback included giving students an opportunity to justify their solution by allowing them to explain their thinking or moving forward in the lesson because all students provided the correct answer and no explanation was needed to explain why the choice was correct. Feedback provided to students is reviewed in more detail in the use of real-time data section of this chapter.

Slight modification to the typical process of formative assessment occurred when George asked students questions through the Navigator System with regards to the *item analysis* and *points earned on an assignment*. Information gathered via the Navigator System for the *item analysis* was not shared with students. Instead, this information was shared and compared with results from other sections of the same course taught by another teacher during a common planning time. The data provided both teachers with an opportunity to determine how students performed on the assessment as a whole and then identify potential areas in which modifications or re-teaching of the material needed to occur. The *item analysis from a quiz* on sequences, inequalities, and sigma notation revealed an area of misunderstanding with regards to question three. As a result of poor student performance across the board, this question would be reassessed at a later time. The ability to collect student data using the *item analysis* helped George determine which questions to focus on and reassess (Post-observation interview, 3/28/14). The *item analysis* could also be used to provide a historical record of how students performed on various concepts throughout the year. Having this electronic record allowed the teacher to go back to prior years and make modifications for the next year to better address the challenges that students faced with each concept. The following vignettes provide testimony to George's use of a *Quick Poll* to gather questions that students missed on a quiz as stated in the pre-observation interview (3/28/14). Content covered on the quiz included Law of Sines, Law of Cosines, and right triangle relationships.

Vignette 1. Using data from item analysis (Pre-observation interview, 3/28/14)

1) T: They are also getting a quiz today and I'm going to make a poll right now for them to tell me which problems they missed.
2) I: Okay
3) T: I know that there are two of them that were really popular that they missed.
4) I: So you're going to give an item analysis again?
5) T: Yeah
6) I: Can you talk just a little bit real quick about how you use item analysis information
7) T: For this what we're going to do is especially because the other Advanced math teacher and I noticed a lot of kids missed three, we're going to re-quiz them on it.
8) I: Okay

9) T: We're going to make them correct their quiz, we always make them correct when they get an assessment back to learn from their mistakes and make those corrections.
10) T: But prior to this year we really weren't good about, we made them correct it and turn it back in to show us they know how to do it, but we've never reassessed them on it before, so that's something different we're doing this year and that's part of the reason we're doing it this year is we've been trained and driven to do more formative assessments and reassessing to see if they've learned it.

In line 1, George planned to make the *Quick Poll* prior to the beginning of the class because he wanted students to select each question(s) or sub-question(s) they missed. Subsequently, in lines 7, 9 and 10 George explained how the information from the *item analysis* was going to be used to inform future review of the content. Specifically, students would correct their quiz, turn in their corrections, and then demonstrate their understanding of the missed concept on a retest at a later time.

George also talked with his students during instruction about the collection of problems they missed from the quiz through the *item analysis* and Navigator System during the classroom observation (3/28/14).

Vignette 2. Informing students about the purpose of the item analysis

1) T: So please, it's for my own benefit to see what problems were most missed and helps me for next year to reemphasize those a little bit more

2) T: Also, I may give you another assessment on these, quiz just to make sure alright you missed it the first time around did they learn from it
3) T: So go ahead and check those off for me send it, make sure you send it
4) T: Again make sure you send that back before you go please

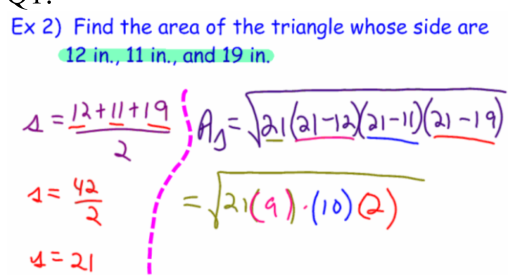
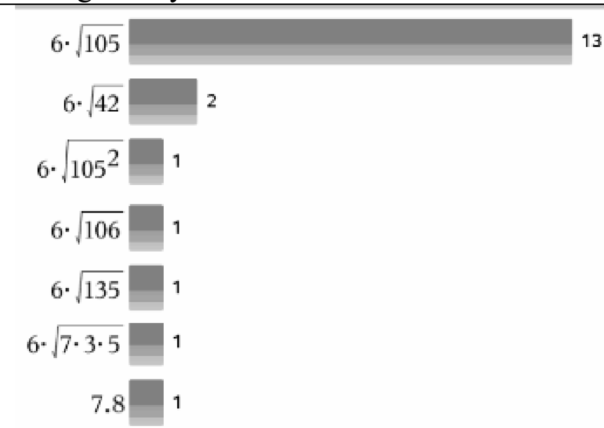
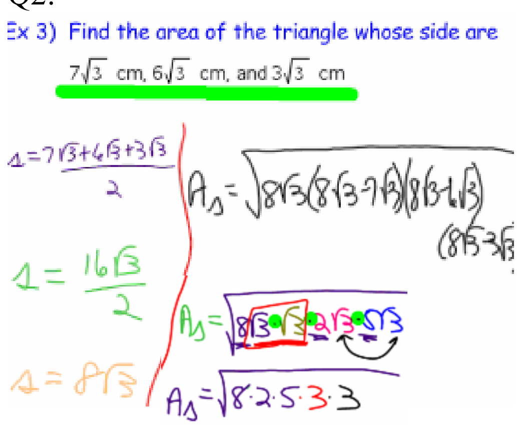
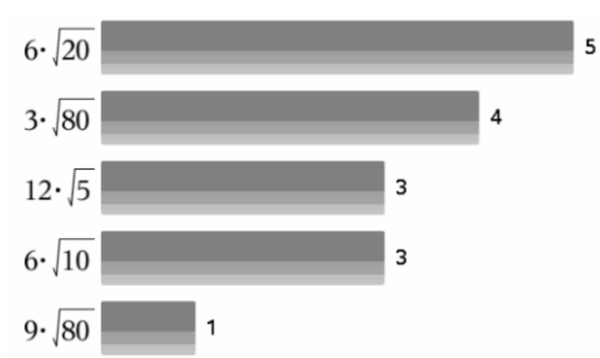
I followed up with George during the post-observation interview to gain a better understanding of how he intended to use the collected data and whether or not he would reassess students on concepts that were missed. The majority of the students missed questions three and ten. George indicated that students would be reassessed on these concepts with the next sections quiz (Post-observation interview, 3/28/14).

George did not share the results of the *item analysis Quick Poll* with students because the intention was for him to use the information to identify gaps in what students understood, share this information with the mathematics teacher who taught the other sections of this course, and determine which questions would need to be reassessed. Although students did not see where the majority of their classmates missed questions, each individual student knew which questions they missed on the assessment because the hard copy was returned to them prior to students entering their missed questions into the *item analysis Quick Poll*. Both teachers identified questions the majority of students missed and decided to reassess the class on these concepts at a later time.

In sum, the formative assessment process that George demonstrated was dominated by the use of *Quick Poll* questions to check for student understanding of the mathematical content being learned during the lesson (KS2). Students moved their desks from rows into groups and were encouraged to collaborate with their peers regularly

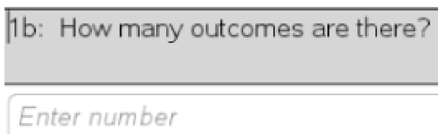
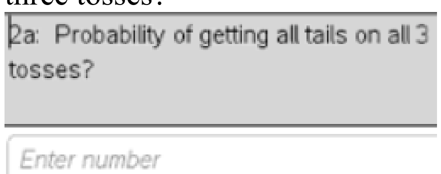
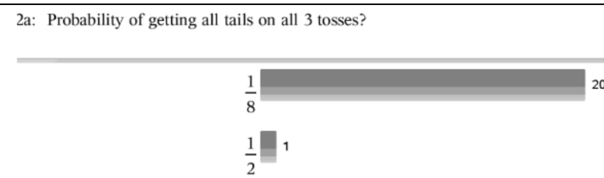
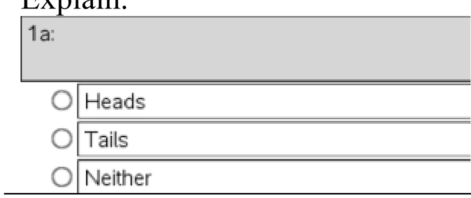
(KS4). Slight modifications were observed in his formative assessment process with regards to the type of feedback that George provided to students as a result of analyzing their real-time data during instruction. Three main forms of feedback George provided to students included *re-teaching, explaining, or scaffolding*, allowing *students to provide a justification* for their response, or *moving forward if everyone correctly answered the question* or stating that an answer was correct (KS3). Additionally, George also used the real-time data from the *item analysis* to decide what needed to be reassessed. Next, I will focus on the *Quick Poll* questions used, the student responses and George's use of real-time data as displayed during the formative assessment process. Table 7 below is a selection of five *Quick Poll* questions that George asked using the TI-Nspire Navigator System to elicit evidence of student understanding and learning (KS2), the student responses as organized and displayed by the system to the class, and the feedback George provided to students after analyzing the real-time data displayed by the Navigator System (KS3). These five *Quick Poll* questions were selected from the 24 *Quick Poll* questions that George gave during the observations. These questions were selected to show the range of feedback that George provided to his students.

Table 7. A selection of George's formative assessment process using Quick Polls

Quick Poll questions asked using TI-Nspire Navigator System	Question Type	Student response as displayed through the Navigator System	George's feedback to students
Q1: 	Gathering information		Re-teach, explain, scaffold
Q2: 	Gathering information		Identify area of difficulty followed by re-teach, explain, scaffold

Continued

Table 7 continued

Q3: If an experiment consists of tossing a fair coin three times and recording the results in order, what is the sample space for this experiment? (Use H for heads and T for tails). How many possible outcomes are there? 	Recall of prior knowledge		Correct answer given, move forward with instruction
Q4: Based on the three diagram, what is the probability of getting tails on all three tosses? 	Gathering information		Correct answer given, followed by re-teach, explain, scaffold
Q5: If the results of the first two coin tosses are heads, are you more likely to toss a head or tail on your third toss? Explain. 	Make a prediction		Student asked to provide justification

George used the real-time data to inform his instruction and the feedback he provided to students. The feedback that George provided to students depended on the number of students who answered correctly to the given *Quick Poll* question and the content being covered. For questions that asked students to *recall their prior knowledge*, if all students answered correctly, George *stated the correct answer and then moved forward with instruction* without further discussing the question and results. However, in lessons in which George *gathered information* from students, even when all, or the majority of students answered correctly he made sure everyone knew why the answer was correct and provided a justification. Question four from above was one example in which the majority of students answered correct, yet George provided a justification for why the answer was one eighth. When students provided several different responses to questions that *gathered information*, such as questions one and two above, George would provide feedback to students by *re-teaching, explaining, or scaffolding* their thinking. The fifth question above asked students to *make a prediction*. The majority of the students provided a correct response, so George asked, "Alright, since the popular answer is neither, can someone explain why you think the answer is neither?" (Observation 3, 3/28/14). The feedback that George provided to students was dependent on student responses and the type of question asked. The system features used, questions asked, and feedback provided to students is summarized in Table 8 below. Additional details regarding George's use of the *Quick Polls* as a formative assessment tool will be shared in the Navigator use section of this chapter.

Table 8. Summary of George's system features, question types, and feedback provided to students

Navigator system feature	Purpose/Question Type	Feedback	Occurrence (Percentage)
Quick Polls	Gathering information (9)	Re-teach, explain, scaffold	7/9 (77.8%)
		Student justification	1/9 (11.1%)
		Teacher identifies difficulty then re-teach, explain, scaffold	1/9 (11/1%)
	Questions from HW (7)	Re-teach, explain, scaffold	5/7 (71.4%)
		No feedback provided	2/7 (28.6%)
	Make a prediction (1)	Student justification	1/1 (100%)
	Item analysis from quiz or test (2)	No feedback provided	2/2 (100%)
	Correct text entry/computations (2)	Verify correct answer then re-teach, explain, scaffold	1/2 (50%)
		Re-teach, explain, scaffold	1/2 (50%)
	Recall of prior knowledge (2)	Verify correct answer and move forward	2/2 (100%)
	Points earned on assignment (1)	No feedback provided	1/1 (100%)

Summary of George's Formative Assessment Process

By using the key strategies of formative assessment as a framework, George demonstrated key strategies two, three, and four when using the TI-Nspire Navigator System. The questions that were used to elicit evidence of student understanding and learning (KS2) and how George used the real-time data to inform instruction and feedback provided to students (KS3) became evident and were dependent on the number of students who answered correctly and the type of question asked. The three main categories of feedback that George provided to students included *re-teaching, explaining, or scaffolding*, *asking students to provide a justification of their solution*, or *confirming a correct answer and moving forward with instruction*. Although key strategy one was stated verbally as a learning target at the beginning of instruction, it was not shared via the technology and thus not included in George's formative assessment process. Likewise, key strategy five was present, but occurred only three times and was not included in the formative assessment process due to the limited number of instances during instruction. George was more likely to encourage students to work together (KS4) then ask students to work independently and reflect on their learning. Next, George's Navigator use in the classroom, which included the frequency and purpose for each system feature used, will be considered.

Navigator Use in the Classroom

There were 31 instances of the Navigator in use during instruction over the course of 14 classroom lesson observations. The main system feature that George used to ask questions and get feedback from students was the *Quick Polls*. This feature was used 77.4% of the time during instruction. The types of *Quick Poll* questions are broken down into seven categories that emerged from the classroom observations and transcriptions data. When considering the *Quick Poll* question type, George used the Navigator System and *Quick Poll* to *gather information* regarding the particular concepts students were learning for the day 37.5% of the time. The second most frequent use of the Navigator System *Quick Poll* feature was to allow students the opportunity to *select questions from their homework assignments* and was used 29.2% during instruction. George gave this question after students had a chance to talk with their group members to try and identify where they made their mistakes, to correct incorrect responses, and talk over how to solve problems they may not have been able to solve on their own. Table 9 below provides a breakdown of the particular system features used and question types or purpose corresponding to each feature of the Navigator System.

Table 9. Summary of system feature and question type frequency for George

Navigator system feature	Number of times observed (percent)	Purpose/Question Type	Number of occurrences, (percent)
Quick Polls	24 (77.4%)	Gathering information	9 (37.5%)
		Questions from HW	7 (29.2%)
		Make a prediction	1 (4.2%)
		Item analysis from quiz or test	2 (8.3%)
		Correct text entry/computations	2 (8.3%)
		Recall of prior knowledge	2 (8.3%)
		Points earned on assignment	1 (4.2%)
Live Presenter	2 (6.5%)	Allow student to control calculator (their pace), get info from student for class to see	2 (100%)
Send/Receive Documents	5 (16.1%)	Send file to students' calculators	4 (80%)
		Retrieve file from students' calculators	1 (20%)
Total	31		

George had seven different ways he utilized the Navigator System to get feedback from students. A summary and example for each of the seven question types will be provided next. When categorizing each of the seven question types, it should be noted that each question was only coded for the primary purpose or question type. Some questions could have been coded for more than one category as a result of the discussions that ensued after the primary question was posed. However, for purposes of this research, each question asked using the Navigator System was coded for its primary purpose based on the initial question.

The most common question type used with the *Quick Poll* feature was for George to *gather information* of the concept being learned for the day's lesson. *Gathering information* was used 9/24 (37.5%) times during instruction. George often worked through examples during class with students and then either asked them to complete the task from a certain point in the problem in which he felt they should be able to finish the question or he asked students to answer a similar question in relation to the concept being learned for that day. During one observation, George asked students to find the area of a triangle whose sides were 12, 15, and 18 units in length using Heron's formula. George and his students worked together to find the semi-perimeter and set up the initial area formula. As a class, they worked until the fourth step in which students were asked to simplify the radical of 45*21*15*9. Figure 6 below is an example of a *gathering information* question that George asked students to finish finding the area of the triangle using Heron's (Hero's) formula from the fourth step. Upon completing the question, students were given a *Quick Poll* and asked to submit their answers through the Navigator System.

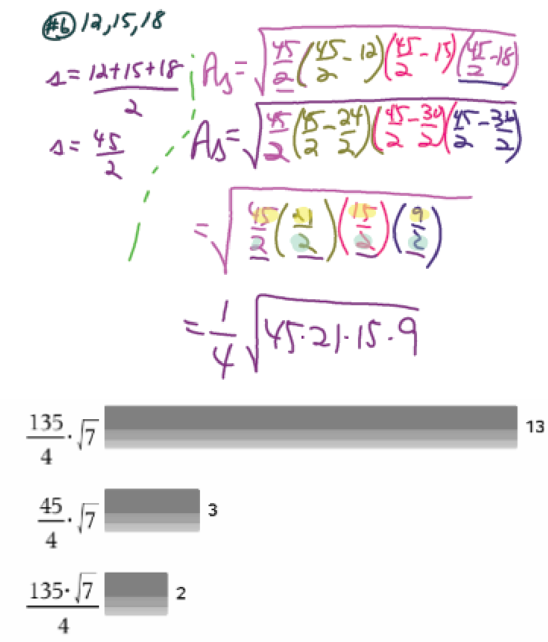


Figure 6. Example of Gathering information question type and student responses.

In this instance, George used the expressions feature of the *Quick Poll* so that students could provide a response based on the work they completed. George began the problem with students but wanted them to continue to simplify. He polled students to see if they could simplify the information under the radical in the fourth line with 45*21*15*9.

The second most prominent use of the *Quick Poll* question was for students to identify *homework questions* they wanted additional help with. *Asking students which questions from homework* they had occurred 7 of 24 (29.2%) times when using the *Quick Polls* feature. George used this feedback to decide which homework questions to cover during instruction. Those questions receiving 4 or more votes would be covered during the lesson. George began with questions that the majority of students had to ensure that the majority of students received help on the homework questions. George also decided the order in which he would cover the questions based on his previous teaching experience and knowledge of student difficulties (Post-observation Interview, 3/28/14). Often times, covering questions that the majority of students had would help students figure out their errors on similar problems, that they were then able to correct on their own. George also retained a record of student question selections. This allowed him to talk with students on an individual basis if they selected a question that no other student had. George could talk with individual students towards the end of class, or at a time when the class worked on homework or some task during the lesson. As needed, students could come in before, during, or after school to get additional assistance. Figure 7 and Figure 8 below provide an example of the *Quick Poll* question sent to students and their responses regarding homework questions.

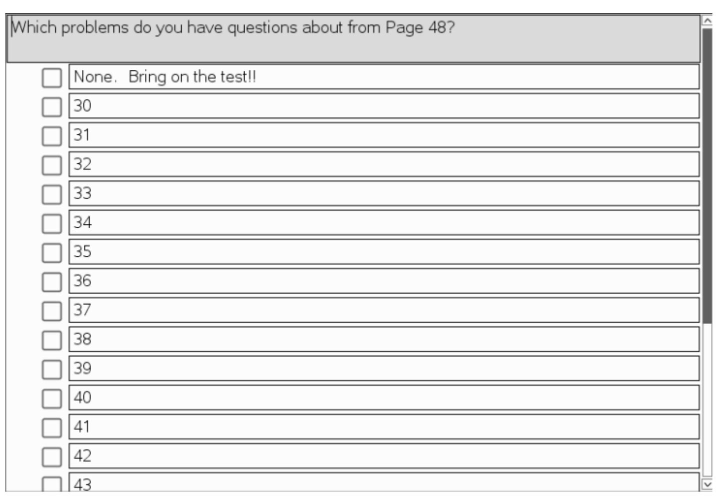


Figure 7. Quick Poll sent to students asking for their homework questions.

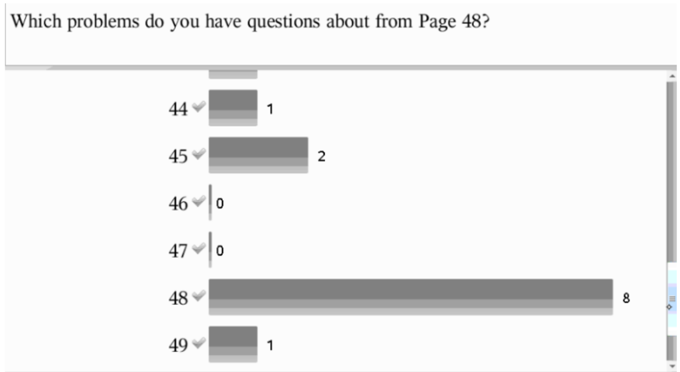


Figure 8. Quick Poll example of student responses regarding homework questions.

The third category in which George used the *Quick Poll* was to have students *make a prediction* in relationship to the mathematical concept they were learning for the day. *Make a prediction* was observed once (4.2%) of the 24 uses of *Quick Polls*. For the example observed during the classroom observation, students were asked to predict the outcome of flipping a fair coin. Specifically, the teacher was interested to know if students flipped a fair coin and got heads on the first two flips, was the third flip more likely to be head, tails, or neither. Figure 9 below provides the *make a prediction* question in which students had to determine the probability of getting tails on all three tosses.

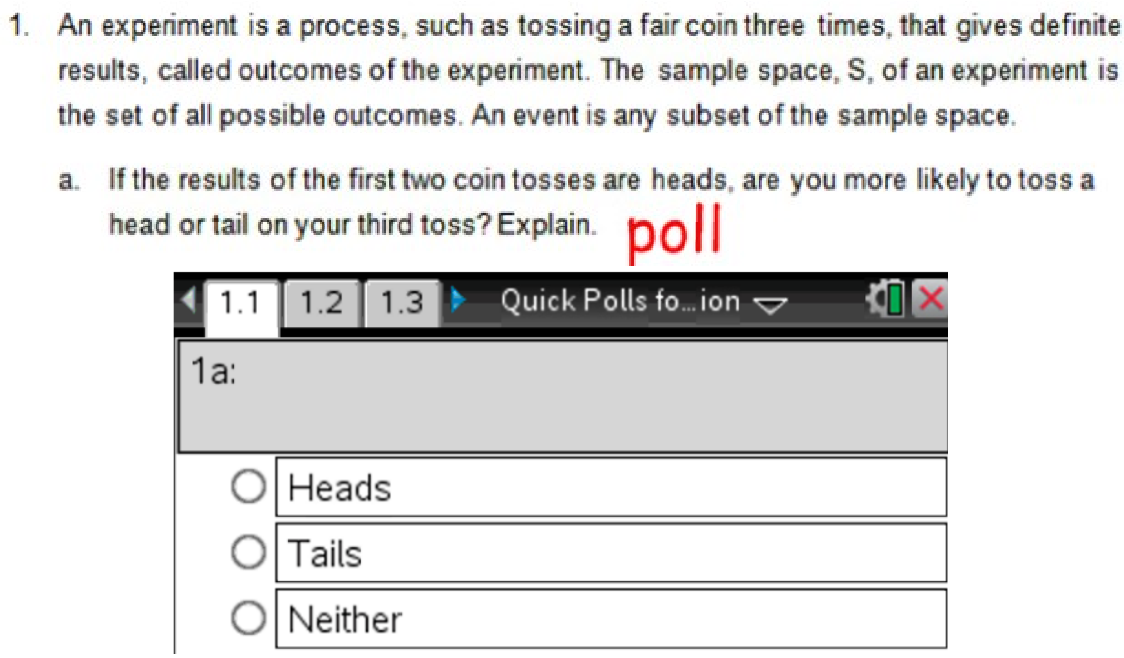


Figure 9. Example of make a prediction Quick Poll question type.

A fourth category in which *Quick Polls* were used was *item analysis from quiz or test*. For this type of question, George identified each question and any subparts so that students could select as many questions and subparts that were missed on the quiz or test. This question type was used twice (8.3%) during the 14 lessons. Although George graded the test himself, having the *item analysis* provided him with an electronic record of his students' performance. He could then share this information with the other mathematics teacher to identify areas that needed to be reassessed across all students in the course. Additionally, having this information allowed for a historical picture of how students performed on the given topic. This would allow the teachers of this class to make adjustments from year to year and then determine if those adjustments supported students in their understanding of the mathematical content. Figure 10 below provides an example of the student responses to the *item analysis* for a quiz over sequences, inequalities and sigma notation. The totals at the end of the bars represent the number of students in this class who missed the question or sub-question(s).

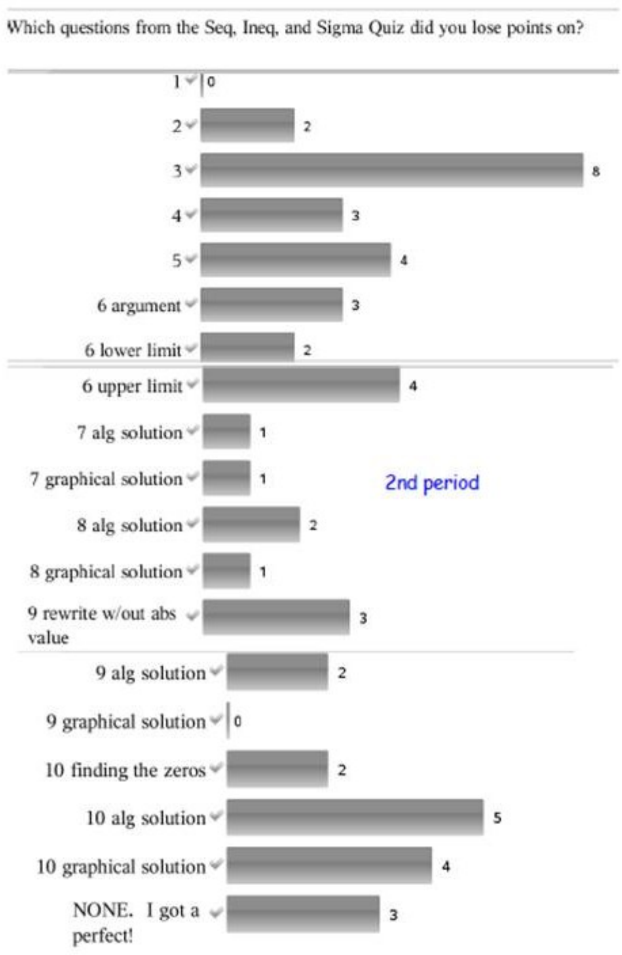


Figure 10. Example of student responses from item analysis for a quiz.

Correct text entry and correct computation was the fifth category of *Quick Poll* question type used by George to assess his students during instruction. George used this type of *Quick Poll* question twice (8.3%) with students to ensure they correctly entered the fractional solution into the calculator. In this particular example, students were asked to solve for t using rules of logarithms. The specific question asked students to:

> Use the exponential decay equation $A = A_0(1/2)^{t/k}$ where A was the amount of a radioactive material present after a time t, k was the half-life, and A_0 was the original amount of the radio-active material and solve the following: An isotope of sodium has a half-life of approximately 3 years. How long will it take an original sample of 9 mg of this isotope to decay to 5 mg? (Observation 4, 5/27/14)

The teacher wanted to make sure students could find the approximate value for t using the calculator. Figure 11 below shows the text that had to be entered into the calculator and students' approximations for t.

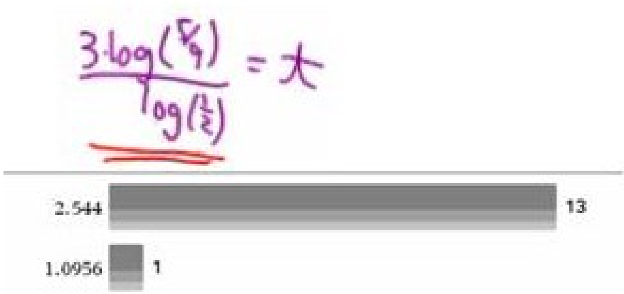


Figure 11. Example of correct text entry/computation Quick Poll question.

The following vignette comes from the classroom observation in which students were asked to enter the value of t into their calculator and to inform students they would be polled on their response.

Vignette 3. Polling students on correct text entry/computation (Observation 4, 5/27/14)

1) T: Go ahead and find the decimal approximation for *t*.
2) T: I'll give you a minute to do that and then I'm going to poll you, so record the answer on paper. I'll poll you to see make sure we can type that in correctly.
3) T: Okay, so you should have the poll hopefully.
4) T: Okay, the correct answer is 2.544

George encouraged the one student who incorrectly typed in the value for *t* to talk with their group members to see what they did and how that was different from their own work. Then, he pulled up the screen capture feature of the Navigator System, was able to identify the error and asked for students to identify the mistake. The student who did not get the correct answer incorrectly typed in the denominator using a 5 instead of a 2 (Observation 4, 5/27/14).

The sixth category, *recall of prior knowledge*, was observed 2/24 (8.3%) times when George used the *Quick Poll* feature of the Navigator System. *Recall of prior knowledge* was an opportunity for students to share knowledge that was learned in the past, but was being assessed in the present. In the vignette below, George asks students to find the sample space for flipping a fair coin three times in a row. Students had already learned how to find the sample space in a previous lesson, hence they are being asked to *recall their prior knowledge* and apply it to the current lesson. George asked students to record the sample space on paper and then determine the number of possible outcomes.

Students used the sample space to help them count the number of possible outcomes. The *Quick Poll* question only asked for the total number of outcomes, not each individual combination of the sample space. Since students had already created sample spaces in the past, George wanted to make sure students could list and total the possible outcomes. The results of the *Quick Poll* showed that all students were able to get eight in the sample space so the teacher was able to move on to the next question in the activity. The vignette below supports this example.

Vignette 4. Example of recall prior knowledge, confirm correct answer and move forward with instruction (Observation 3, 3/28/14)

1) T: If an experiment consists of tossing a fair coin which just means a regular coin okay, three times and recording the results in order, what is the sample space for this experiment?
2) T: Do that on your paper right now. You've done this enough times to be able to do this right?
3) T: Go ahead and find the sample space for tossing a coin three times.
4) T: So go ahead and do that on your own right now.
5) T: Alright, question 1b says how many outcomes are there? So go ahead and tell me how many outcomes there are just to make sure we are on the right page here.
6) T: You should have them all listed, right now I just want to know how many are there.

7) T: Okay, everyone agrees there are 8 outcomes, okay?

8) T: Good, we've done that plenty of times.

The final *Quick Poll* question type observed in George's lessons asked students to record their *points earned on an assignment*. This question type was observed once (4.2%) during instruction. In this lesson, students were given a rubric specific to a free response question from the AP Calculus released items and asked to exchange their work with a partner, grade each other's work using the rubric, and then record the points they earned using the Navigator System once they received their paper back. This opportunity was more for students to get used to the scoring rubric for the AP exam, but the feedback provided to George allowed him to see how students were doing on their first attempt to solve a free response question. Figure 12 below provides student responses to the number of points they earned on the free response question that was graded by a partner.

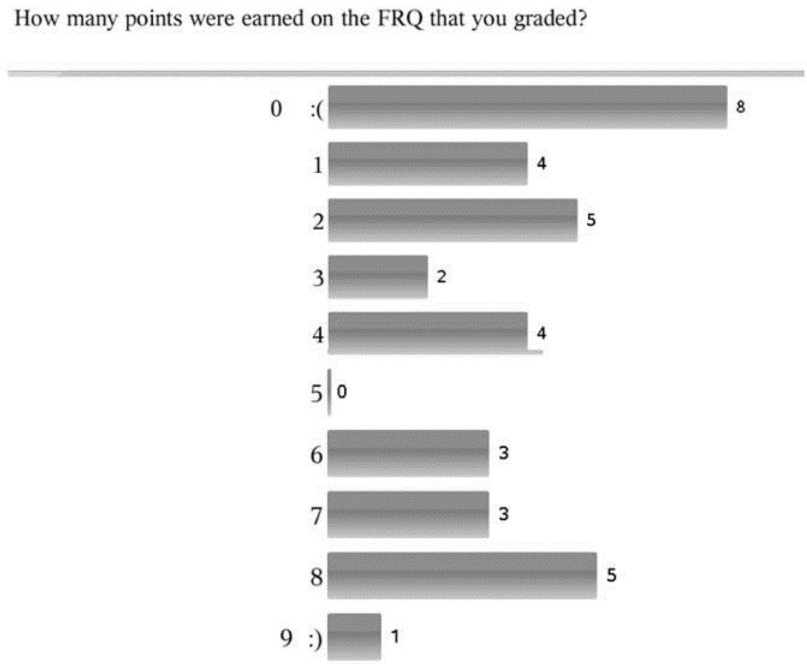


Figure 12. Example of student responses to the number of points earned on assignment.

The Navigator System allowed George to retain a record of how students performed during instruction. George was able to work through examples with students as well as provide them with an opportunity to work in their groups as they solved examples on various mathematical concepts. Then George sent a *Quick Poll* question to students as a way to *gather information* and check if they could solve the problem from a given point in the example, or to identify whether or not students understood the concept they were working on. Additionally, *Quick Polls* were used to gather information from students that could be used by the teacher or other teachers who teach the same courses as a way to determine what areas might need to be reassessed through the use of the *item analysis from quiz or test*, *points earned on an assignment*, and *correct text* *entry/computation*. George also used the features of the Navigator System as he asked students to *make a prediction* or *recall their prior knowledge*. George found seven different ways to use the *Quick Poll* feature of the Navigator System to formatively assess his students.

Summary of George's Navigator Use in the Classroom

The primary way that George used the Navigator System during instruction was to give seven different types of *Quick Poll* questions. For a list of the seven different types of questions, refer to Table 8 on page 74. Of the 31 instances of Navigator use during instruction, *Quick Polls* were used 24 (77.4%) times. When considering each of the seven types of questions asked, the majority of the *Quick Poll* questions were given to *gather information* (37.5%) and to get questions from students regarding homework assignments (29.2%). This suggests that George wanted to make sure his students learned the daily content by trying practice problems as a means to identify if students could correctly answer the examples. He also took questions students had from homework and reviewed questions the majority of students had. In both cases, George shared the results of the *Quick Polls* with students and then used that information to provide feedback and to focus on areas of difficulty. In addition to *Quick Polls*, the *Live Presenter* feature was used twice during instruction. However, this feature was not used for assessment purposes. Instead, it was used to help students with computations on the calculator. The third feature used was to *Send/Receive Documents*. This feature was also not used for assessment purposes during instruction. George found seven different ways he could use *Quick Polls* to formatively assess his students during instruction. He then used their responses to inform his instruction and the feedback he provided to them. Additional results regarding feedback will be shared in the real-time data section of this chapter.

Navigator Use and Planning Continuum

The continuum of unplanned to planned assessments as suggested by Shavelson et al. (2008) was used to determine if the 31 instances of Navigator use were *planned-for-interaction* prior to the lesson, created *on-the-fly* during instruction, or were *embedded-in-the-curriculum*. The questions asked using the 24 *Quick Polls* lend themselves to being analyzed using this continuum. However, George did not use the Navigator System features of *Live Presenter* or *Sending/Receiving Documents* as a formative assessment tool during his instruction. Thus, only the 24 *Quick Poll* questions were analyzed using the planning continuum.

There were 24 instances of the *Quick Polls* in use by George over the 14 lessons. Those questions that were created *on-the-fly* included four of nine (44.4%) *gathering information* and one *correct text entry/computations* question. Questions that were *planned-for-interaction* and created using the Navigator System prior to each lesson included three *gathering information* questions (33.3%), both *item analysis* questions, the second *correct text entry/computation* question, and one of the *recall of prior knowledge* questions. Finally, two *gathering information* questions were *embedded-in-the-curriculum* as well as all seven (100%) of the *Quick Polls* used to get *student questions from homework* and the one question in which students submitted the *number of points earned* on a free response item from the released AP Calculus materials. During one lesson, George incorporated a pre-made file on theoretical and experimental probabilities that was available through Texas Instruments. The file was shared with students via the

Navigator System. However, the file itself did not require the teacher to use the *Quick Polls* feature to get feedback from students. Instead, the teacher chose to use the Navigator System *Quick Polls* to retrieve students' input for each of those questions. However, since the questions were listed in the file and corresponding worksheet, they were coded as *embedded-in-the-curriculum* because George created *Quick Poll* questions directly from the worksheet. Therefore, one of the *recall of prior knowledge* questions was also *embedded-in-the-curriculum* because it came from a curriculum resource. Table 10 below provides a summary of different question types asked using the *Quick Polls* feature of the Navigator System and the number of questions that were created *on-the-fly*, *planned-for-interaction*, or *embedded-in-the-curriculum*.

Table 10. Summary of George's Quick Poll questions and planning continuum

Navigator system feature	Purpose/Question Type	Number of occurrences	On-the-fly	Planned-for-interaction	Embedded-in-the-curriculum
Quick Polls	Gathering information	9/24 (37.5%)	4 (44.4%)	3 (33.3%)	2 (22.2%)
	Questions from HW	7/24 (29.2%)			7/7 (100%)
	Make a prediction	1/24 (4.2%)			1 (100%)
	Item analysis from quiz or test	2/24 (8.3%)		2/2 (100%)	
	Correct text entry/computation	2/24 (8.3%)	1/2 (50%)	1/2 (50%)	
	Recall of prior knowledge	2/24 (8.3%)		1/2 (50%)	1/2 (50%)
	Points earned on assignment	1/24 (4.2%)			1/1 (100%)

The *Quick Poll* questions to *gather information* were created *on-the-fly* using the equations and expressions built-in question template feature of the Navigator System. Specifically, an expression question in which students could provide a numeric response was created *on-the-fly* and sent to students via a *Quick Poll* so they could provide the teacher with feedback in regards to simplifying Heron's formula for finding the area of a triangle. Each poll was not created prior to the lesson. Instead, they were created while the lesson was occurring, hence making them an *on-the-fly Quick Poll*. The same poll was sent to students a second time during this lesson as students finished the rest of the problem and George wanted to check for their understanding. George used this poll again a third time to check that students could simplify under the radical with regards to Heron's formula (Observation 1, 2/13/14). George also used a *Quick Poll* that was created *on-the-fly* to *gather information* with regards to finding the definite integral in his AP calculus course. In the applied math class, *Quick Poll* questions were created *on-the-fly* to *gather information* from students as it related to Heron's formula (Observation 1, 2/13/14).

When getting students *questions from homework*, all *Quick Polls* were *embedded-in-the-curriculum*. George would list all question numbers in the *Quick Poll* and then ask students to select those questions they had questions on. The polls were also created prior to the lesson and referenced the problem numbers from the course textbook. Students then selected the question numbers they wanted help with. The following vignette provides an example of how George used the *Quick Poll* to gather students' *questions from the homework* assignment (Observation 1, 2/13/14).

Vignette 5. Using Quick Poll to get homework questions from students

1) T: I am going to send you one more poll, although I might not be able to address it today. I want to know what questions you have here. We will probably start Tuesday if I see there are a lot of questions on these. I won't have time to do the item analysis we will do that on Tuesday also.
2) T: I sent you a poll asking you what questions you have on not just 10 through 17 but 1 through 17. The law of cosines stuff too. So make sure you send that back to me so I know what questions you have. Your assignment is the back of page 39 1-15 odds I believe they are all hero's type formula. I want exact and approximate answers.

With regards to the *points earned on an assignment*, George created a *Quick Poll* in which students had the option to select the number of points they earned on the free response question in which they had to grade each other's homework using a rubric for the question that was released for the AP exam. Since this question was from the AP curriculum, the question was *embedded-in-the-curriculum*. The first *recall of prior knowledge* question asked students to consider the research they did the day before this lesson and what they remembered from their research and was *planned-for-interaction* (Observation 1, 2/13/14). The second *recall of prior knowledge* question came from a Texas Instruments resource and hence was *embedded-in-the-curriculum*.

The results of Table 10 show that 7 of the 24 questions (29.2%) that George asked using the *Quick Polls* feature of the Navigator System were *planned-for-interaction*.

There were 5/24 (20.8%) questions created *on-the-fly* and 12 of 24 questions (50%) *embedded-in-the-curriculum*. When *gathering information*, George tended to create questions *on-the-fly* indicating that while going through examples with students during instruction there were moments he wanted to determine if students could answer questions correctly on the content being learned.

As an alternative, when George wanted to collect data regarding questions students missed in the form of an *item analysis from quiz or test*, to *recall their prior knowledge*, or verify the *correct text entry or computation* on the calculator, he used polls created prior to instruction. There were also assessments that were *embedded-in-the-curriculum* and used during instruction. These included two *gathering information* questions, all seven *homework* questions, the *make a prediction question*, one of the *recall of prior knowledge* questions and the *points earned on assignment* question. In one lesson, George used a pre-made file that was sent to students graphing calculators using the Navigator System and had students complete a complimentary worksheet that had questions on it for students to consider regarding theoretical and experimental probabilities. However, George incorporated the use of *Quick Polls* to get feedback from students regarding several of the questions that were on the worksheet even though it was not recommended to use the Navigator System to collect feedback from students. This included the two *gathering information* questions, one of the *recall of prior knowledge* questions and the one *make a prediction* question. The 24 *Quick Poll* questions lent themselves to the planning continuum and provided examples of the different types of questions that could be asked using the Navigator System.

Summary of Navigator Use and Planning Continuum

The majority of *Quick Poll* questions used by George were *embedded-in-the-curriculum* and included two questions to *gather information*, seven *homework questions*, one *make a prediction* question, one *recall of prior knowledge* question, and one *points earned on assignment* question. These 12 questions were *embedded-in-the-curriculum* because they came from curriculum or supplementary resources, such as the AP free response question, and were used by George to assess his students. The polls themselves were created by George, but the information for which the questions were based came from curriculum and supplementary resources. Questions that were *planned-for-interaction* were created by George prior to instruction and included three *gathering information* questions, two *item analysis* questions, one *correct text entry/computation* question, and one *recall of prior knowledge* question. The difference between the *planned-for-interaction* and *embedded-in-the-curriculum* questions was based on the origin of the content. Both questions were created prior to instruction, but George developed *planned-for-interaction* questions whereas the *embedded-in-the-curriculum* questions came from a curriculum or other resource. Finally, questions created *on-the-fly* during instruction include four *gathering information* questions and one *correct text entry/computation* question.

As displayed in Table 10 on page 90, questions that were *embedded-in-the-curriculum* tended to give George information regarding student understanding of the content and homework assignments by taking *questions from homework* and asking student to r*ecord points earned on an assignment*. When *gathering information*, George tended to ask questions *on-the-fly* indicating the need to assess students in the moment during instruction. Additionally, George planned prior to instruction different questions he wanted to give students that would *gather information* from students, ask them to *recall prior knowledge*, and determine if they could *correctly enter* information into the calculator. When using *Quick Polls* George would plan prior to instruction the questions he wanted to ask students. Next, George's use of real-time data will be shared.

Use of Real-Time Data

There were 19 instances of how George responded to the feedback he received from his students during instruction while the Navigator System was in use. These 19 instances feel into three main categories that included *re-teach, explain scaffold*, *confirm correct answer and move forward with instruction*, and *ask students to provide a justification*. In turn, this became feedback that George provided to students to help support their understanding of the various content being learned during each lesson. As with the question types, the initial feedback provided to students was used as the unit of analysis to categorize the feedback. A description for each type of feedback will be provided, including an example of each. Then the level of feedback as described by the feedback level framework of Lee (2012) will be provided.

Most prominent was for George to re-*teach, provide the explanation, or scaffold* students' understanding by asking them questions for each step to finish out the example problem. This form of feedback occurred 78.9% of the time when George used the Navigator System. Within the category of *re-teach, explain, scaffold* there were three distinct instances in which George made an initial comment focused on certain aspects of the real-time data followed by *re-teach, explain, and scaffold*. During the first instance, George identified the area of difficulty students had towards the end of the lesson with simplifying radicals. In another lesson, George first stated the given answer was correct, but followed that up immediately with an explanation of why. Third, George considered the differences in student responses and then he proceeded to *re-teach, explain, and scaffold* students thinking for the given example. In addition to George leading the discussions by *re-teaching, explaining, or scaffolding*, students were asked to *justify their solution* 2/19 (10.5%) times during instruction. The last form of feedback provided to students was observed twice during instruction (10.5%) and included *moving forward with instruction because everyone correctly answered* the question or stating that a given response was the correct answer. Table 11 provides a summary of the types of feedback that George provided to the class once he received feedback from students through the *Quick Polls*.

Table 11. Summary of George's feedback to students

George's feedback to students	Number of occurrences (percent)	Feedback breakdown	Number of occurrences (percent)
Re-teach, explain, scaffold	15/19 (78.9%)	Re-teach, explain, scaffold	12/15 (80%)
		Identify difficulty followed by re-teach, explain, scaffold	1/15 (6.7%)
		Verify correct answer followed by re-teach, explain, scaffold	1/15 (6.7%)
		Address differences in answers then re-teach, explain, scaffold	1/15 (6.7%)

Continued

Table 11 continued

Student provides justification	2/19 (10.5%)	NA	NA
Confirm correct answer and move forward with learning	2/19 (10.5%)	NA	NA

Below are instances of each of the three types of feedback George provided to his students during instruction after reviewing their real-time data collected, organized, and displayed through the Navigator System. The first and most prominent was for George to *re-teach, explain, or scaffold* students' understanding through the example problem being covered in class. This type of feedback occurred 78.9% of the time when George provided feedback to students. This type of feedback was given during a lesson in which students were asked to find the area of a triangle given the measures of the three side lengths using Heron's (Hero's) formula. Since the example dealt with radicals, the teacher worked through part of the example with students, but then asked them to simplify from the third step below in which no radicals were under the radical. Then he polled the students and although 17 students, out of 18 students in attendance that day, successfully simplified the radical, the teacher continued to explain how to correctly simplify (Observation 1, 2/13/14). The original question asked students to find the area of a triangle using Heron's formula when the side lengths were $7\sqrt{3}$, $6\sqrt{3}$, and $3\sqrt{3}$. As a class, the semi-perimeter was found together and the initial setup of the area formula and first two steps to simplify were also completed together. Figure 13 below provides the example problem students were working on and their responses to simplifying the radical 3*3*8*2*5.

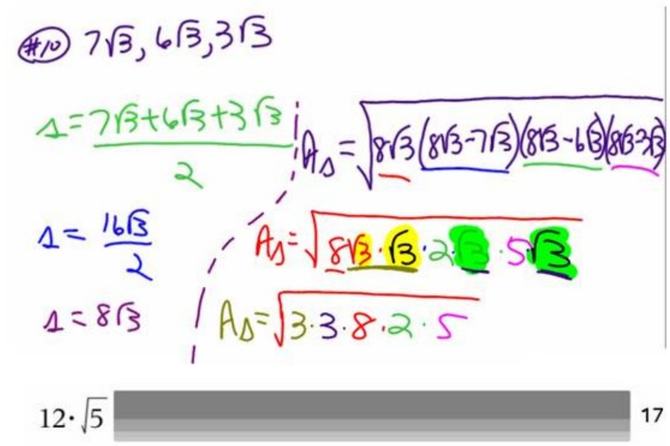


Figure 13. Question and feedback from students that provoked George to re-teach, explain, scaffold.

The following vignette comes from the same lesson and supports the feedback of *re-teaching, explaining, and scaffolding* that George provided as a result of 17/18 students providing a response of 12√5.

1) T: So from here I want you to take it and find the correct answer. You should be able to get the rest of it, okay?
2) T: If you're ready, I just sent it to you [Quick Poll question]
3) T: Alright so all 16 of you got the answer of 12 radical 5.
4) T: 17 of you now have 12 radical 5
5) T: Okay, let's just make sure?
6) T: So, we can't leave this unfinished here
7) T: Did you break this down any further, the 8 part? Did you do that?
8) T: Some of you may or may not have to do that. So 3 times 3 times here maybe four times two times another two times five

9) T: There are other ways you can do this, you don't have to do it this way all the time
10) T: Some of you might have looked and said that's just what? 16. And the square root of 16 is what? Four. So you can bring out a four. That's fine too.
11) T: But I have a pair of three's and I have a pair of two's
12) T: So a pair of threes bring that out gives me a three, a pair of twos bring that out is 2, square root of four is 2. The only radical left is a five.
13) T: So that gives me 12 radical 5 and that's square units.

There were also three additional instances when George would *re-teach, explain, and scaffold*. However, this action followed an initial reaction to the real-time data. In the same lesson in which students used Heron's formula to find the area of a triangle, students worked through another example and provided their responses via a *Quick Poll gathering information* question. Upon reviewing the real-time data, George stated that, "So we still need help simplifying" and then proceeded to explain why one answer was not simplified that led into his explanation and re-teaching for how to correctly simplify the radical (Observation 1, 2/13/14).

The second instance in which *re-teach, explain, scaffold* was preceded by a comment was during a lesson on theoretical and experimental probabilities. During this lesson, students were simulating coin flips and asked various questions. One *Quick Poll* question asked students to determine the probability of getting tails on all three tosses when tossing a fair coin. After reviewing the real-time data George commented, "Alright, the correct answer is one eighth. So let's make sure we understand why it's one eighth"

(Observation 3, 3/28/14). He then proceeded to provide the explanation for why one eighth was correct.

The third instance that George *re-taught, explained, or scaffolded* students' thinking was during a lesson on application problems within the context of exponential growth and decay. In this lesson, students had to use rules of logarithms to solve exponential equations. George polled students to see if they could *correctly enter text* into the calculator for a difficult computation. The poll asked for their numeric response. Upon reviewing the real-time data, George stated, "So these two have different answers. This one has the same, this is the same. Looks like most of you got 2.54 round the 4, or 2.5440. Let's see how we get that." (Observation 4, 5/27/14). George then continued to work with students and explained how to correctly solve the problem to get the answer of 2.5440.

A second form of feedback observed during instruction was for students to have an opportunity to *justify the answer* they provided through the Navigator System. In this example, students were asked to make a prediction for flipping a fair coin three times and whether the first two flips would impact the results of the third. The question, poll sent to students, and their response are provided in Figure 14 below. Then, George asked for one student to explain the popular answer of neither in the vignette below (Observation 3, 3/28/14).

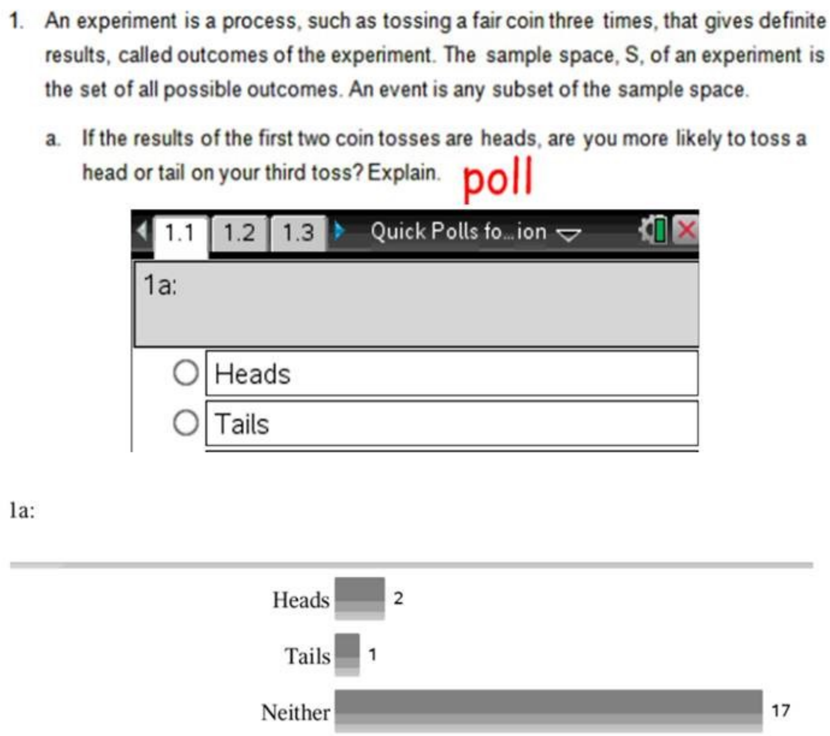


Figure 14. Question, Quick Poll, and student responses for an example in which George asked for a student justification for the choice of neither.

Vignette 6. Student justification for solution (Observation 3, 3/28/14)

1) T: So a, if the results of the first two, let's say your tossing a coin three times if the results of the first two coin tosses are heads, so you flip a coin, it's heads you flip a coin, it's heads. The question is this, are you more likely to toss a head or tail on your third toss?
2) T: So quietly within your pairs discuss if the first flip is a head, the second flip is a head, is it more likely for the third one to be a head or tail? Go ahead and talk that over.

3) T: And I’m going to poll you.
4) T: Alright, so I sent you a poll giving you three options either you think the next ones going to come up heads or you’re going to say its tails or neither one is more likely than the other.
5) T: Alright, most of you say neither.
6) T: A couple people say heads, one person thinks it’s going to be tails.
7) T: Alright, so since the popular answer is neither can someone explain why you think the answer is neither.
8) T: Go ahead
9) MS: The previous attempts have absolutely no effect on the further ones. It doesn’t say that it has to be the chance of getting two heads in a row. The other two flips, they don’t even matter. You are flipping the same coin. It should have the same affect.
10) T: So whatever happens on the first couple flips does that have any effect on the next flip? No.
11) T: The coin doesn’t know what happened right on the previous flips. It’s not like hey you went heads the first couple of times we got to change it up here, right? No it doesn’t know, okay?
12) T: Those are called independent events.

The final type of feedback that was observed in George’s lessons was to *move forward* in the lesson if all students had answered the question correctly. This was observed twice of the nineteen instances in which feedback was provided to students. The vignette and Figure 15 below provide an example of the question, *Quick Poll*, student feedback, and George's comments that indicated they would *move forward* with the lesson without the need to explain why the given answer was correct (Observation 3, 3/28/14).

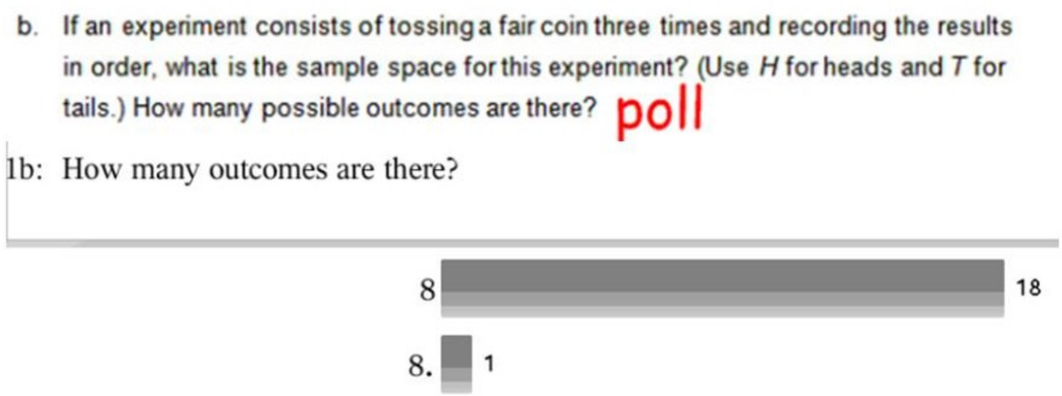


Figure 15. Quick Poll and student feedback used by George to determine he could move forward with instruction because everyone answered correctly.

Vignette 7. Move forward because everyone answered correctly

1) T: If an experiment consists of tossing a fair coin which just means a regular coin okay, three times and recording the results in order, what is the sample space for this experiment?
2) T: Do that on your paper right now. You've done this enough times to be able to do this right?
3) T: Go ahead and find the sample space for tossing a coin three times.
4) T: So go ahead and do that on your own right now.

5) T: Alright, question 1b says how many outcomes are there? So go ahead and tell me how many outcomes there are just to make sure we are on the right page here.
6) T: You should have them all listed, right now I just want to know how many are there.
7) T: Okay, everyone agrees there are 8 outcomes, okay?
8) T: Good, we've done that plenty of times.
9) T: Someone thinks it's 8 point but that's great. Same thing
10) T: Alright, on your paper you should have the sample space and write down that there are 8 outcomes.
11) T: Alright, the next question.

Once George saw that everyone had the correct response of 8, he asked them to write that answer down on their paper and then they proceeded to the next question. He did not feel the need to *re-teach, explain, or scaffold* student thinking because finding the sample space was something they had done plenty of times and this was just one way to make sure they were okay with finding the sample space in a different context. Once he saw the results, he knew that all students were okay and that they could move forward in the lesson.

The previous examples provide insight to the three types of feedback observed during instruction in George's classroom. In two of the three instances, the feedback was initiated by George. These included *re-teaching, explaining, or scaffolding* students understanding towards a solution and confirming that the answer provided by all students was correct and *moving forward* in the lesson. The third instance of feedback was student generated in that George provided students with an opportunity to *justify their solution* and to give an explanation to the entire class. Next, the level of feedback that George provided to his students will be discussed.

Lee's (2012) three levels of feedback are *evaluative/normative*, *corrective/verification* or *elaborative/facilitative*. Of the 19 times that George provided feedback to students after a *Quick Poll* question, *corrective/verification*, or level two feedback occurred 26.3% (5/19) of the time during instruction. Level two feedback focused on identifying student difficulties when simplifying radicals, *confirming the correct answer and moving forward with learning*, and *asking student to provide a justification*, or to verify, the most popular answer. The most prominent form of feedback provided to students was level three, or *elaborative/facilitative* feedback. Level three feedback occurred 73.7% (14/19) of the time and included *re-teaching, explaining, or scaffolding* student thinking. This also included the two subsets of addressing differences in answers and verifying the correct answer immediately followed by the *re-teaching, explaining, or scaffolding* of the mathematical content for that day. There were no instances of level one, or *evaluative/normative* feedback observed during George's instruction. The categories of feedback that he provided to students during instruction are summarized below in

Table 12.

Table 12. Summary of George's feedback categorized by level

System feature used	Feedback level	George's feedback to students	Number of occurrences (percent)
Quick Polls	One	None	0%
	Two	Identify difficulty followed by re-teach, explain, scaffold	1/19 (5.3%)
		Confirm correct answer and move forward with learning	2/19 (10.5%)
		Student provides justification	2/19 (10.5%)
	Three	Re-teach, explain, scaffold	12/19 (63.2%)
		Address differences in answers then re-teach, explain, scaffold	1/19 (5.3%)
		Verify correct answer followed by re-teach, explain, scaffold	1/19 (5.3%)

Summary of George's Use of Real-Time Data

The primary way that George provided feedback to students was to *re-teach, explain, or scaffold* their thinking. This type of feedback was *elaborative/facilitative*, or level three feedback, because George provided additional commentary after reviewing the real-time data to help students better understand the mathematical concepts being learned that day. Upon closer inspection of this category, three distinct instances that included additional comments occurred followed by the *re-teaching, explaining, or scaffolding* of students understanding. These three additional instances included *identify an area of difficulty* for students with simplifying radicals, a *verification of the correct* *answer followed by an explanation, and discussing differences in answers* and then *re-teaching, explaining, and scaffolding*. The second way that George provided feedback was to ask students to *provide a justification* for their solution. This occurred twice during instruction and was *corrective/verification*, or level two feedback. In each case, students were asked to verify that the most popular answer was the correct response. Finally, *moving forward with instruction by confirming the correct answer* was the final form of feedback that George provided to his students. This feedback was also level two feedback. There were no instances of level one feedback present during George's instruction. Next, a compilation of George's question types, planning continuum, and feedback will be shared

Putting it All Together

In this section, we will look at George's entire formative assessment process from the question types asked through his use of the real-time data and feedback provided to students. George displayed one main formative assessment process that incorporated key strategies two, three, and four. George would begin class by verbally stating the learning intentions, or learning targets as he referred to them, with students. Although this first key strategy was present during instruction, because the learning targets were not shared via the technology, they did not appear in his formative assessment process. After the learning targets were shared, George typically asked students to move their desks from rows into groups. Then the class would work through examples together, or students would work with their groups to review and correct homework (KS4). It was during this time that George would elicit evidence of student understanding and learning (KS2) by using the Navigator System to send a variety of *Quick Poll* questions to students. Once students submitted their responses, George could analyze the real-time data collected, organized, and displayed by the Navigator System and provide feedback to students (KS3). The three main categories of feedback that George provided to students were *re-teach, explain, scaffold*, *ask students to provide a justification*, and *confirm the correct answer and move forward with learning*. These three forms of feedback were at levels two and three. No level one feedback occurred during instruction. Table 13 summarizes the *Quick Poll* questions asked, the planning continuum, and feedback provided to students. The question types represent key strategy two of the formative assessment framework and feedback represents key strategy three.

Table 13. Summary of George's question types, planning continuum, and feedback

Navigator system feature	Purpose/Question Type	Planning continuum	Feedback and level	Occurrence (percent)
Quick Polls	Gathering information (9)	On-the-fly (4)	Re-teach, explain, scaffold L3	4/4 (100%)
		Planned-for-interaction (3)	Student provides justification L2	1/3 (33.3%)
			Re-teach, explain, scaffold L3	2/3 (66.7%)
		Embedded-in-the-curriculum (2)	Re-teach, explain, scaffold L3	2/2 (100%)
	Questions from HW (7)	Embedded-in-the-curriculum (7)	No feedback provided	2/7 (28.6%)
			Re-teach, explain, scaffold L3	5/7 (71.4%)
	Make a prediction (1)	Embedded-in-the-curriculum (1)	Student provides justification L2	1/1 (100%)

Continued

Table 13 continued

	Item analysis from quiz or test (2)	Planned-for-interaction (2)	No feedback provided	2/2 (100%)
	Correct text entry/computation (2)	On-the-fly (1)	Verify correct answer followed by re-teach, explain, scaffold L3	1/1 (100%)
		Planned-for-interaction (1)	Address differences in answers then re-teach, explain, scaffold L3	1/1 (100%)
	Recall of prior knowledge (2)	Planned-for-interaction (1)	Confirm correct answer and move forward L2	1/1 (100%)
		Embedded-in-the-curriculum (1)	Confirm correct answer and move forward L2	1/1 (100%)
	Points earned on assignment (1)	Embedded-in-the-curriculum (1)	No feedback provided	1/1 (100%)

George used the Navigator System *Quick Polls* in seven different ways during instruction. Questions that were created *on-the-fly* during instruction included four *gathering information* questions and one *correct text entry/computation* question. George responded to all five of these questions with *elaborative/facilitative* feedback as he *re-taught, explained, or scaffolded* students' thinking. *Quick Poll* questions that were *planned-for-interaction* include three *gathering information* questions, both *item analysis* questions, one of the *correct text entry/computation* questions, and one *recall of prior knowledge* question. There was no feedback provided for *item analysis* questions, but level two and three feedback for the other questions. The *embedded-in-the-curriculum* questions included two *gathering information* questions, all seven of the *questions from* *homework*, the *make a prediction* question, one *recall of prior knowledge* question, and the *points earned on assignment* question. For these questions, George provided no feedback, level two feedback, or level three feedback, depending on the question. The Navigator System allowed for the collection, organization, and display of real-time data that George used to inform his instruction and feedback provided to students. The *Quick Poll* questions helped him elicit evidence of student understanding and learning (KS2). He then used the real-time data to provide three types of feedback to students (KS3). These questions accounted for 24 of the 31 instances in which the Navigator System was used during instruction by George as he implemented formative assessment into instruction.

Chapter 5: The Case of Zoe

Chapter 5 explores the case of Zoe. This chapter will include background information regarding Zoe's teaching experience, the evolution of technology within her classroom to support the teaching and learning of mathematics, and a description of the classes that were observed in which the data came from. Following the introductory material and information about Zoe, her process of formative assessment when using the TI-Nspire Navigator System will be presented followed by a closer look at the key strategies present during the use of the technology. Second, her use of the technology as a formative assessment tool, including the system features used and question types asked will be provided. Third, Zoe's use of real-time data to inform instruction and the feedback she provided to students will be shared. I begin with Zoe's background and educational information.

Zoe is a secondary mathematics teacher with nine years of teaching experience, eight of which she served in her current district located in a Midwestern state. At the time of this study, it marked her sixth year of integrating the TI-Nspire Navigator System into instruction. Zoe earned a bachelor's degree in mathematics and also obtained her licensure for teaching mathematics in grades 7-12. She has continued to pursue additional education at the graduate level and is interested in curriculum development and professional development of teachers. Zoe works in a small town district that is characterized by her state department of education as low student poverty and small student population. Zoe has a classroom set of 30 TI-Nspire graphing calculators that students are allowed to sign-out on an as needed basis during regular school hours. However, due to large class sizes, the number of calculators that can be signed out by other students throughout the day is limited. This version of graphing calculator has an interchangeable faceplate and can also function as a TI-84 so other teachers in the district can use the classroom set of calculators.

Technology has evolved in Zoe's classroom over the past eight years. When she began her career in her current district, she had a chalkboard. In her second year, she was given a SMART Board, which she has integrated into her instruction for the past seven years. After attending professional development and receiving a grant, the TI-Nspire Navigator System and student graphing calculators were acquired and integrated into her Statistics courses during her third year of teaching. Zoe has continued to teach statistics using the graphing calculators and Navigator System. During her fourth year, she introduced her Geometry students to the calculator and has continued to use them with these students today. Finally, students in her Advanced Quantitative Reasoning course have used the graphing calculators for the past three years. Next, details regarding the classroom observations will be shared.

Classroom Observations

I had the opportunity to observe Zoe teach 17 statistics lessons that were 42 minutes in length during the Fall of 2014. Students enrolled in this course were required to have Algebra II as a prerequisite. The majority of the students enrolled in the course were seniors. The course content is based on the AP statistics curriculum; however, this is a college preparation course for statistics, not an AP statistics course.

During the classroom observations I focused on Zoe's use of the Navigator System to identify her formative assessment process as supported by the technology. This included identifying the key strategies of formative assessment that were present during instruction while the TI-Nspire Navigator System was in use, Zoe's process of formative assessment, the system features used, questions asked, and Zoe's use of real-time data to inform subsequent instruction. There were 37 instances of the Navigator System in use during 8 of the 17 lessons that I observed. The results reported here are representative of those 37 instances. Next, I will focus on the key strategies of formative assessment that occurred during Zoe's instruction while the TI-Nspire Navigator System was in use and describe her process of formative assessment using the technology.

The Process of Formative Assessment

The five key strategies of formative assessment include: 1) clarifying and sharing learning intentions and criteria for success, 2) engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning, 3) providing feedback that moves learners forward, 4) activating students as instructional resources for one another, and 5) activating students as the owners of their own learning (Black & Wiliam, 2009). This framework was used to code each of the 17 classroom observations as a means to identify which of the key strategies were present during instruction when the TI-Nspire Navigator System was in use. Key strategies that were present during instruction, but not when the technology was in use are also noted below. Next I will describe the presence of each key strategy during instruction and how Zoe's process of formative assessment when using the Navigator System integrated these key strategies.

Zoe used the Navigator System in 8 of the 17 lessons that I observed. In all eight lessons, she verbally clarified and shared the learning intentions and criteria for success with students typically at the beginning of the class. The learning intentions were either statements of content to be covered during instruction, or student expectations to be accomplished by the end of class. It should be noted that the learning intentions were not delivered to students using the Navigator System. Instead, the teacher shared this information verbally with students. One such example of sharing the learning intentions with students at the beginning of class came from a lesson in which students reduced a set of data to determine which characteristic from a given list of attributes would best predict the weight of a given object. This learning intention was a statement informing students they should be able to find the line of best fit for various scatter plots and use that information to determine which attribute was the best predictor for the weight of the object. Zoe shared this learning intention by stating, “We’re going to try to come up with a line of best fit. This is our goal with our data.” (Observation 2, 10/14/14).

The only instance when the learning intentions were not shared at the beginning of class occurred in a lesson in which the teacher began by going over questions from the previous night’s homework assignment. Once all questions from homework were answered, a shift towards the day’s lesson and learning a new, but related topic occurred. Zoe then informed students that they needed to get their notes out for the new topic and that students would be learning about permutations for the rest of class. The example below is the learning intention that was shared with students about permutations.

Vignette 8. Sharing of learning intentions with students (Observation 9, 10/31/14)

1) T: Get your notes out. You have your permutation notes. I want those out, and we'll do those next.
2) T: We're going to talk about permutations today.

The transmission of verbal learning intentions is reflected in Zoe's formative assessment process as no learning intentions or criteria for success appeared. Next, the classroom discussions, questions, and tasks that Zoe used to elicit evidence of student understanding and learning will be shared.

The second key strategy is engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning. The primary way that Zoe elicited evidence of student understanding and learning was to pose questions in the form of examples to students after they discussed the day's topic or worked through examples as a class. The purpose of each example was to *gather information* from students in relationship to the mathematical content being learned. Zoe used the *Quick Polls* feature of the Navigator System to *gather information* from students. Students were asked to enter and submit their numeric response for each question using the calculator. Zoe then shared the results with the class and used their responses to inform her instruction and feedback. The use of discussion occurred after students provided a response to an example, and was used as a means to allow students to explain how they achieved their solution or to guide students through the solution strategy by questioning facilitated by the teacher. Details regarding the *Quick Polls* questions will be discussed in more detail in the Navigator use section of this chapter. Next, an overview of the feedback that Zoe provided to students will be shared.

The third key strategy of formative assessment is providing feedback that moves learners forward. In this section, an overview of the feedback that Zoe provided to her students will be shared. A more in depth description of the feedback provided to students will be shared in the use of real-time data section of this chapter. The type of feedback provided to students depended on the system feature that was used. The three primary system features that Zoe used to elicit evidence of student understanding and learning included the *Live Presenter*, *Quick Polls*, and *Screen Capture*. By using these features, Zoe was able to monitor student progress and pose questions about mathematical content as a means to gain insight to their understanding of the material. She then used the feedback students provided through the three features to inform her instruction and provide feedback to students. There were three main forms of feedback provided to students when using the *Live Presenter* and *Quick Polls* feature of the system. This included *confirming a correct answer*, *asking students to provide a justification* for their solution, or the *teacher providing a reason for why someone answered incorrectly*. Zoe tended to provide feedback that was *corrective/verification*, or level two, after reviewing student answers for the *Quick Polls*. When the *Screen Capture* feature was used, Zoe *monitored student progress*, *provided feedback on the multiple representations* that were being used to answer questions, and *used information from the students' screens as a springboard into class discussion*. The majority of the feedback provided to students as a result of using the *Screen Capture* feature was *evaluative/normative,* or level one.

Activating students as instructional resources for one another is the fourth key strategy of the formative assessment framework. Zoe encouraged students to work together or if they chose to solve a problem on their own, to check their solution with someone near to them once they finished. Zoe would provide comments such as “work it out, talk to the people around you” (Observation 7, 10/29/14), “check with the person next to you, if this makes sense, go for it” (Observation 7, 10/29/14), “Try the next two examples on your own. Then check with the person next to you to make sure you guys have the same answer” (Observation 9, 10/31/14), and “I want you to work with another person. Six minutes, go ahead and work with each other, talk out this confusing stuff and then we will go ahead and we’ll do a *Quick Poll*” (Observation 10, 11/3/14). When the Navigator System was in use, students would often have time to work on examples first, encouraged to work together or check solutions with one another, and then submit their solutions at a later time via a *Quick Poll* question.

In addition to encouraging students to talk with one another and work together, when students had different answers, she encouraged them to defend their response to their partner to convince them they were correct or to argue their point of view. During one lesson, students worked on an example problem dealing with permutations. As Zoe walked around the classroom, she noticed that several students were getting different answers. She encouraged students to activate one another as instructional resources by saying “talk to each other about why you’re getting different answers” [Observation 9, 10/31/14]. In another lesson, Zoe intentionally did not provide enough copies of the handout for all students because she wanted them to communicate with one another and argue their point of view. “So I want you guys to get into your groups. I intentionally did not run copies for everyone single person because I want you guys to look on the same copy and I want you to converse and argue with each other" (Observation 2, 10/14/14). To activate students as instructional resources for one another, Zoe provided verbal cues to students throughout instruction as she encouraged them to work together, check their solutions with one another, and argue their point of view. These verbal cues were also present during instances when the Navigator System was in use, as Zoe wanted to make sure students continued these practices prior to submitting their solutions via the *Quick Poll* questions.

Activating students as the owners of their own learning is the final key strategy of the formative assessment framework. Zoe tended to use this key strategy fewer times then the previous key strategy because she wanted students to communicate their ideas with other students, work together to solve the problems, or check their work with a partner. Once the class completed the day's notes and examples, they were given additional questions to try individually or with others. Hence, students were activated as the owners of their own learning on these additional examples. By giving students an opportunity to work through examples on their own and then check with a person near to them, Zoe could identify areas of difficulty for students. There were three instances in which she preferred that students solve the example problems individually first, but this was always followed by asking students to check with someone near to them. She provided verbal cues for the students so they would solve the problems individually. Instances of this included the following comments, "I want to go ahead and give you guys the opportunity to try the next one on your own" (Observation 7, 10/29/14), "Work on it, then talk to the person next to you and compare your answers" (Observation 7, 10/29/14), and "I want you guys to go ahead and try the next two examples on your own" (Observation 9, 10/31/14). By allowing students to work individually first, students could determine whether or not they understood the concept, then confirm their solutions with a partner, and then reflect on their process if needed. Next, I will consider how each of the five key strategies helped shape Zoe's formative assessment process.

Zoe demonstrated two distinct formative assessment processes when using the TI-Nspire Navigator System, dependent upon the system feature being used. The first typical formative assessment process occurred in lessons that incorporated the *Live Presenter* and *Quick Polls* features of the Navigator System and is presented below in Figure 16.

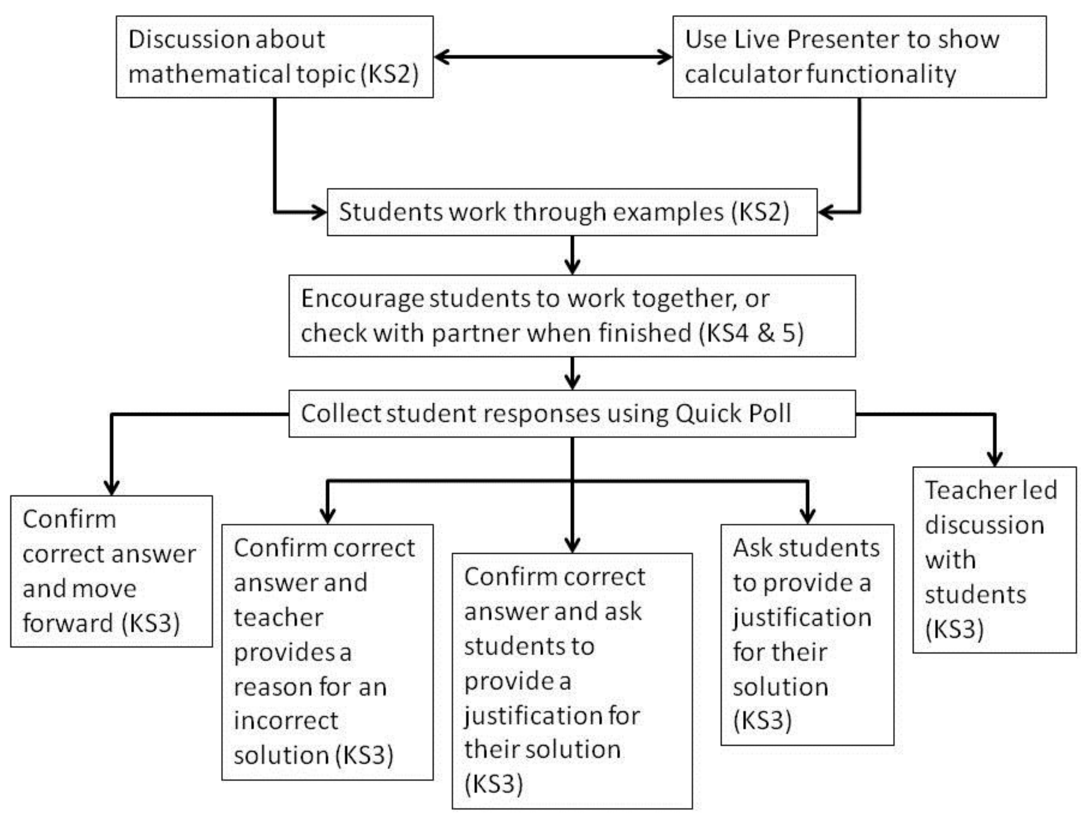


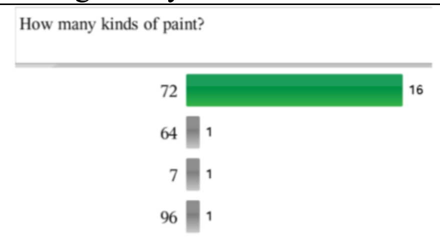
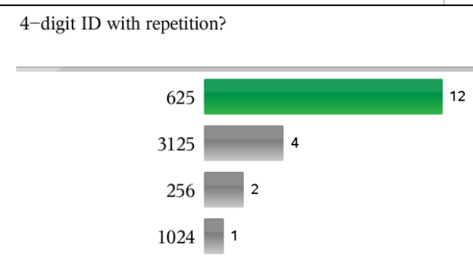
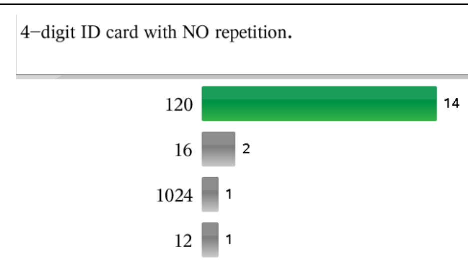
Figure 16. Zoe's formative assessment process when using Live Presenter and Quick Poll system features.

Zoe's formative assessment process when using *Live Presenter* and *Quick Poll* system features included key strategies two, three, four, and five of the formative assessment framework. Although the first key strategy of sharing learning intentions and criteria for success were not shared via the technology, the teacher shared them verbally with students. Since this first key strategy was not delivered via the Navigator System, it does not appear in Zoe's formative assessment process above.

In the *Live Presenter* and *Quick Polls* formative assessment process, Zoe typically began class by engineering effective classroom discussions, questions, and learning tasks to elicit evidence of student understanding and learning (KS2). Zoe used a combination of classroom discussions and giving students questions in the form of examples to work through together as a class. Zoe would also have students run the live presenter feature of the Navigator System as the class learned how to use different features of the calculator to help with their statistics calculations. By allowing different students to be the *Live Presenter*, they learned at their own pace. After the facilitation of whole-class discussions, working through class notes and examples together, and using the *Live Presenter* to do so, students were given an opportunity to continue with additional examples on their own or with a partner (KS2). During this time, students were encouraged to act as instructional resources for one another (KS4) and be instructional resources for themselves (KS5). Once students worked through the examples and talked with students near to them to compare their solutions, Zoe would send her students a *Quick Poll* question via the Navigator System to *gather information* from students with respect to the mathematical content students were learning that day. Zoe displayed student responses for everyone to see. She then used this real-time data to provide feedback to students (KS3). The feedback Zoe provided to students included a *confirmation of the correct answer* followed by a request of students to explain their solution, Zoe providing a *reason for an incorrect student response*, or to *move forward with instruction because everyone answered correctly*. In addition to the confirmation feedback, Zoe also provided feedback to students that asked them to *provide a justification* for their solution or used their results to facilitate a class discussion on how they might solve the given problem. A more in depth look of the system features used, questions asked, and Zoe's use of the real-time data will occur in three subsequent sections of this chapter. Next, I will focus on the *Quick Poll* questions used, the student responses and Zoe's use of real-time data to inform her instruction as displayed during the formative assessment process.

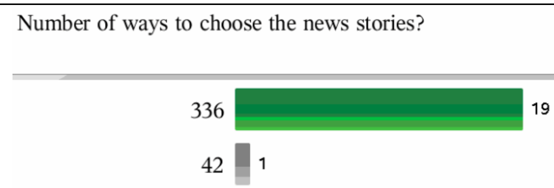
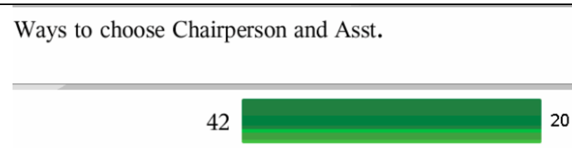
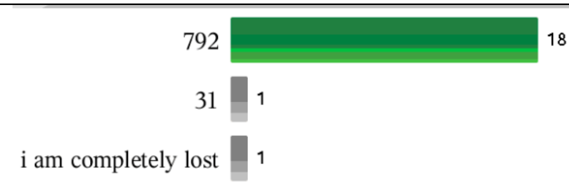
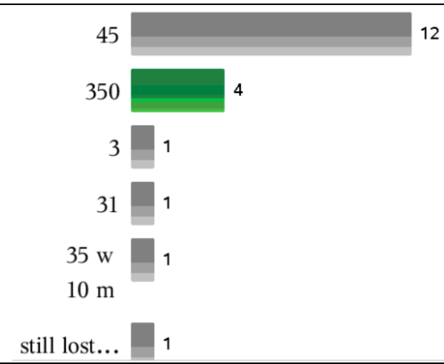
Table 14 is a collection of the ten Quick Poll questions that Zoe asked using the TI-Nspire Navigator System to elicit evidence of student understanding and learning (KS2), the student responses as organized and displayed by the system to the class, and how Zoe used the real-time student responses to inform her instruction as well as the feedback she provided to her students (KS3).

Table 14. Zoe’s formative assessment process when using Quick Polls

Quick Poll question asked using TI-Nspire Navigator System	Student response as displayed through the Navigator System	Zoe’s feedback to students
Q1: How many different kinds of paint can be made if a person can select one color, one type, one texture, and one use?		Confirm correct answer and ask students to explain their solution
Q2: The digits 0, 1, 2, 3, and 4 are to be used in a four-digit ID card. How many different cards are possible if repetitions are permitted?		Ask students to provide a justification for their solution
Q3: The digits 0, 1, 2, 3, and 4 are to be used in a four-digit ID card. How many different cards are possible if repetitions are NOT permitted?		Confirm correct answer and ask students to explain their solution

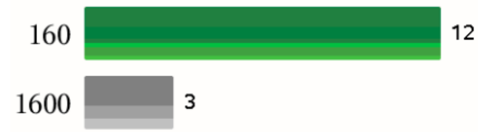
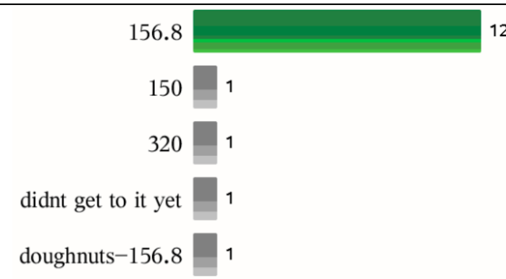
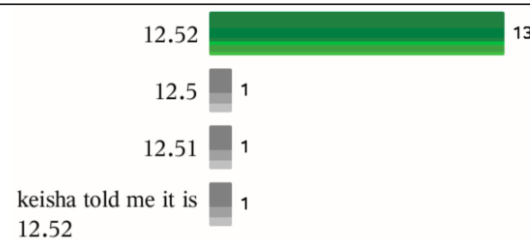
Continued

Table 14 continued

Q4: A television news director wishes to use 3 news stories on an evening show. One story will be the lead, one will be the 2nd, and the last will be the closing story. If the director has a total of 8 stories to choose from, how many possible ways can the program be set up?		Confirm correct answer and provide a justification for an incorrect student submission
Q5: How many different ways can a chairperson and an assistant chairperson be selected for a research project if there are 7 scientists available?		Confirm correct answer and move forward with instruction
Q6: A bicycle show owner has 12 mountain bicycles in the showroom. The owner wishes to select 5 of them to display at a bicycle show. How many different ways can a group of 5 be selected?		Confirm correct answer and move forward with instruction
Q7: In a club there are 7 women and 5 men. A committee of 3 women and 2 men is to be chosen. How many different possibilities are there?		Teacher led discussion with students

Continued

Table 14 continued

Q8: The Statistical Bulletin published by Metropolitan Life Insurance Co. reported that 2% of all American births result in twins. If a random sample of 8000 births is taken, find the mean, variance, and standard deviation of the number of births that would result in twins. What is the mean?		Confirm correct answer and provide reason for incorrect student response
Q9: What is the variance?		Confirm correct answer and provide reason for incorrect student response
Q10: What is the standard deviation?		Confirm correct answer and move forward with instruction

Zoe's use of real-time student responses to inform her instruction and the types of feedback she provided to students depended on the number of students who provided a correct answer to the given *Quick Poll* question. Questions in which the majority of students answered correctly, no more than two students answered incorrectly, Zoe would state the answer was correct and proceed to the next example, or continue with the material to be discussed for the day's lesson without any additional discussion for that question/example. There was one exception to this pattern. For question 4, one student provided an incorrect answer, which happened to be the answer to the next *Quick Poll* question. Zoe stated that, "my guess is someone just answered the next question" as a reason for the incorrect student submission and then proceeded forward with instruction (Observation 9, 10/31/14). For those questions in which three to seven students answered incorrectly, Zoe provided three forms of feedback. She would 1) *confirm the correct answer immediately followed by a request from students to explain their solution*, 2) *confirm the correct answer and then she would provide a reason why students may have submitted an incorrect response*, or 3) she would ask *students to explain their strategy* for getting the correct answer. The final way that Zoe used the real-time student responses to inform her instruction occurred when only four students correctly answered the *Quick Poll* question. Zoe used the different student responses as a way to lead into a whole-class discussion that she facilitated. The anonymity of the Navigator System allowed for these discussions to occur. Zoe stated that, "This is why I like anonymity. This is a good one to talk about because we have some different opinions" (Observation 10, 11/3/14). From here, Zoe used the incorrect answers to help students understand why their answers were incorrect and what they needed to do to correctly solve this problem. The vignette below is an example of how Zoe used the incorrect student responses from a question about combinations to help students understand how they could correctly solve the problem.

Vignette 9. Using student responses to lead class discussion (Observation 10, 11/3/14)

1) T: So when you guys did seven choose three, which both of you got 45, I can tell that you did this part right.
2) T: When you got seven choose three, what number did that give you?
3) T: And when you do five choose two what does that give you?
4) T: Now, the key to this is when you have a committee with men and women on it for every one woman that you choose you have to talk about all the ways you can choose another woman and another man to be on the committee.
5) T: This is a tree diagram idea.
6) T: When we've done tree diagrams what do we do with the number? Multiply or add them?

By using the key strategies of formative assessment as a framework, Zoe demonstrated key strategies two, three, four, and five when using the *Live Presenter* and *Quick Polls* feature of the Navigator System. When focusing in on the *Quick Poll* questions themselves, the questions that were used to elicit evidence of student understanding and learning (KS2) and how Zoe used real-time data to inform her instruction and the feedback she provided to her students (KS3) became evident and were dependent upon the number of students who correctly answered the questions. Although key strategy one, clarifying and sharing learning intentions and criteria for success, was not shared with students via the technology and did not appear in Zoe's formative assessment process, it was stated verbally by Zoe at the beginning of class. Zoe's second formative assessment process will be shared next.

The second formative assessment process demonstrated by Zoe occurred when she used the *Screen Capture* feature of the Navigator System. Prior to using the technology, Zoe would begin class by verbally sharing the learning intentions (KS1) with students. Again, this key strategy does not appear in Zoe's formative assessment process because technology was not used to share the learning intentions. The key strategies present during Zoe's second formative assessment process included eliciting evidence of student understanding and learning (KS2), providing feedback to move learning forward (KS3), and activating students as instructional resources for one another (KS4) and is represented by Figure 17.

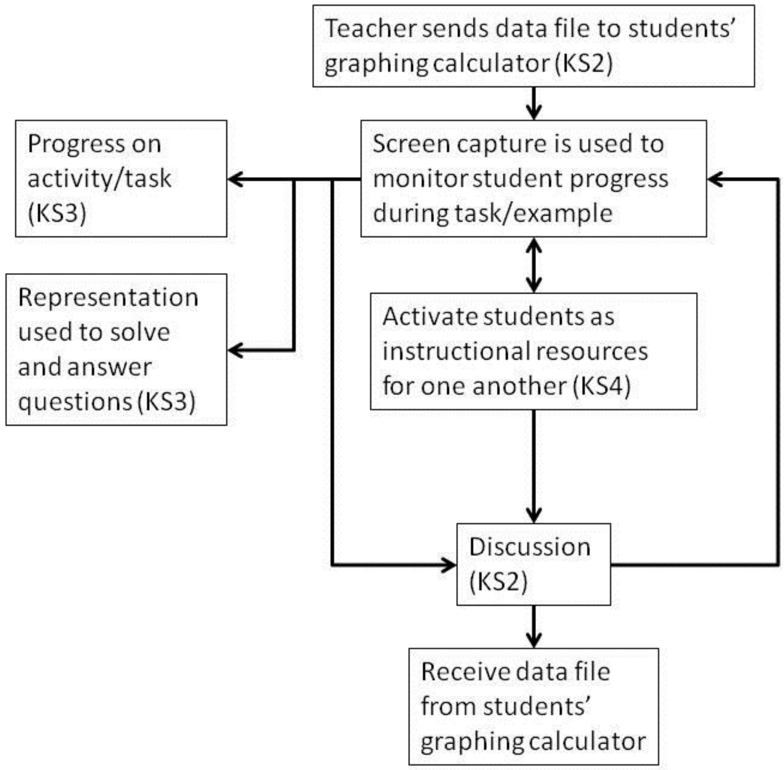


Figure 17. Zoe's formative assessment process when using Screen Capture.

The second formative assessment process began with the transfer of files to the students' graphing calculators. Students then worked through various questions that were given to elicit evidence of student understanding and learning with regards to the statistical concepts being learned for the day (KS2). The *Screen Capture* feature allowed Zoe to display all logged in students screens up on the board for the class to see. From here, Zoe, as well as other students, could monitor the progress of students as they worked through the given tasks. After the tasks had been assigned, Zoe would also encourage students to work together (KS4). The *Screen Capture* feature allowed Zoe to provide verbal feedback to students on their progress with regards to completion of the assignment or the different representations that groups were using the help answer questions (KS3). The information shared on the *Screen Capture* helped inform the conversations that Zoe had with students about the mathematical concepts they were learning. At this point in the lesson, if time allowed, this process would repeat with another example. At the end of the lesson, Zoe would recollect files from the students' calculators so they could be redistributed during the next class session. The system features used, questions asked, and feedback provided to students for both formative assessment processes are summarized in Table 15 below. Additional details regarding Zoe's use of the *Screen Capture* feature as a formative assessment tool will be shared in the Navigator use section of this chapter.

Table 15. Summary of Zoe's system features, question types, and feedback provided to students

Navigator system feature	Purpose/ Question Type	Feedback	Occurrence (percentage)
Quick Polls	Gathering information (10)	Confirm Correct	8/10 (80%)
		Ask student to provide justification	1/10 (10%)
		Teacher led discussion with students	1/10 (10%)
Screen Capture	Monitor student progress (6)	Monitor student progress	6/6 (100%)
	Use screen capture to lead into discussion (1)	Use screen capture to lead into discussion	1/1 (100%)

Summary of Zoe's Formative Assessment Process

Zoe had two formative assessment processes that were observed during her instruction. The process used was dependent upon the Navigator System feature in use. The first formative assessment process incorporated the *Live Presenter* and *Quick Polls* features of the system. When this process was used, key strategies two through five were present. Although key strategy one was not shared via the Navigator System, it was stated verbally by Zoe, typically at the beginning of the lesson. This also occurred during the second formative assessment process when the *Screen Capture* feature of the system was used. During the second formative assessment process, key strategies two, three and four were observed. By eliciting evidence of student understanding and learning, Zoe took advantage of the system features to ask questions and receive feedback from all students who provided a response. From their responses, she made informed decisions based on this real-time data to inform her instruction. The ways that Zoe moved forward with instruction depended on how many students correctly responded to the *Quick Poll* questions she asked. The feedback she provided included *confirming correct answers*, *asking students to provide a justification* for their solution, and using *student responses to lead a whole-class discussion*. Additional details regarding feedback will be shared in the use of real-time data section of this chapter. Overall, Zoe's formative assessment processes integrated three and four of the five key strategies of the formative assessment framework. Next, Zoe's Navigator use in the classroom, which included the frequency and purpose for each system feature used, will be considered.

Navigator Use in the Classroom

There were 37 instances of Navigator use during instruction. The most prominent system feature used by Zoe was *Live Presenter*, followed by *Quick Polls*, *Screen Capture*, *Sending/Receiving Documents*, and using the login screen to take attendance. Table 16 below provides a breakdown of the particular system features used and question types or purpose corresponding to each feature of the Navigator System.

Table 16. Summary of system feature and question type frequency for Zoe

Navigator system feature	Number of times observed (percent)	Purpose/Question Type	Number of occurrences (percent)
Quick Polls	10 (27%)	Gathering information	10/10 (100%)
Screen Capture	7 (18.9%)	Monitor student progress	6/7 (85.7%)
		Use sc to lead into discussion	1/7 (14.3%)
Live Presenter	12 (32.4%)	Allow student to control calculator (their pace)	12/12 (100%)
Send/Receive Documents	6 (16.2%)	Send file to students' calculators	3/6 (50%)
		Retrieve file from students' calculators	3/6 (50%)
Login Screen	2 (5.4%)	Take attendance	2/2 (100%)
Total	37		

Zoe used the *Live Presenter* feature of the Navigator System as an instructional tool to help students learn how to use various features of the graphing calculator with respect to statistics concepts 12/37 (32.4%) times during instruction. These included using the *Live Presenter* to help students learn how to reduce and analyze data for prediction-making purposes and for answering questions and examples specific to the fundamental counting rule, finding probabilities for at least, the compliment, combinations, permutations, and binomial distribution. The purpose for using the *Live Presenter* was to help students become familiar with the functionality of the calculator and to be able to use it to find various probabilities for the given questions. The following two vignettes provide examples of using the *Live Presenter* feature to reduce data and find a combination. In the vignette below, Zoe walks the student through how to delete data from the file that students have on their graphing calculator. Students determine which data to keep and which data to eliminate based on the criteria they decide as a group.

Vignette 10. Using Live Presenter with students (Observation 2, 10/14/14)

1) T: I'm going to pick someone just randomly, I don't have your names on here.
2) T: You are going to be our leader. Welcome fearless leader.
3) T: He is going to show us how to delete the data that we don't want.
4) T: You can do this in a spreadsheet; you can do it here on the calculator.
5) T: He's going to go up to the very first row by hitting control 7
6) T: We want to keep the one where the circumference is 54. We decided that was our best piece of data and that was very subjective; we all had thoughts on that.
7) T: So here's what he's going to do. He's going to go left, left until that whole thing is highlighted and guess what, you're going to be doing the same thing.

8) T: So everyone on your calculator go to the very left and highlight that whole first row.
9) T: You know you're on row one because it says one right here.
10) T: So all of row one, go left.
11) T: Now, what did you just do to get rid of all those numbers?
12) T: You can press delete.

The next vignette provides an example of Zoe randomly choosing a student to run the *Live Presenter* feature of the system to help answer a question about finding the number of different combinations if four objects are taken two at a time.

Vignette 11. Randomly selecting a student to run the Live Presenter (Observation 10, 11/3/14)

1) T: I want someone to help me out.
2) T: If I have four choose two, if I have four choose two let's have this person right here, can you show me how you just got that?
3) T: What were the keys that you hit to plug in 4 choose 2?

The *Quick Polls* were the second most frequently used feature during instruction. Zoe used the *Quick Polls* 10/37 (27%) times during instruction to gather information from students regarding various statistics topics. Since Zoe had previously taught the course, she had created example questions for students to try after the class finished taking notes and discussing the concepts for the day. Usually students worked through an example or two with the teacher and then were given additional examples to try on their own, check with a partner, provide feedback to the teacher and then proceed with the lesson based on the feedback. The following examples support Zoe's gathering information question using the *Quick Polls* feature of the Navigator System. During this lesson, students were applying the knowledge they had gained earlier during the lesson to determine the number of different kinds of paint that can be made from selecting one color given six choices, one type given two choices, one texture given three textures and one use given two choices. Figure 18 provides the *Quick Poll* question given to students to gather information of the fundamental counting rule with the additional question information provided to students via class notes.

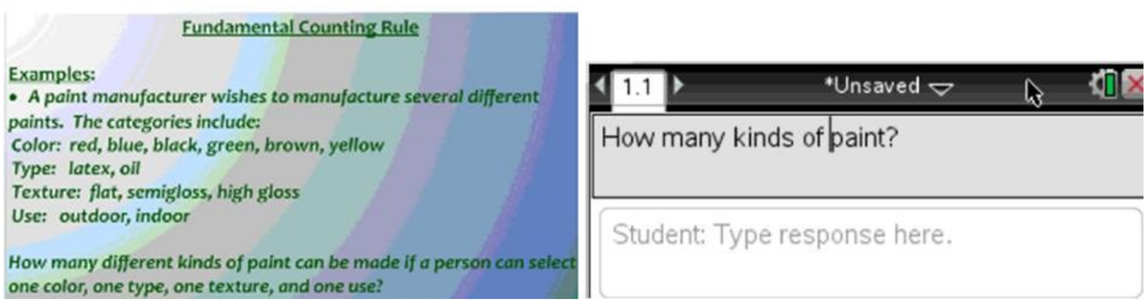


Figure 18. Quick Poll question example from notes and Navigator System.

The *Screen Capture* feature was the third more frequently used Navigator System feature by Zoe at 7/37 (18.9%) uses. Of these 7 instances, 6 were to monitor the progress of students while they worked during class. Zoe stated that by using the *Screen Capture* it helped to keep students on task and accountable for completing their work and it allowed her to monitor their progress and provide feedback to students based on the work they demonstrated through their calculator screens. The vignette that follows is an example of monitoring student progress throughout the lesson using the *Screen Capture* feature of the Navigator System while students reduced a set of data as a way to determine which characteristics might best determine the weight of an object.

Vignette 12. Monitoring student progress using Screen Capture (Observation 1, 10/10/14)

1) T: I'm curious to see how you are working through problems on your calculator so I'm going to put this up here [*Screen Capture* feature].

2) T: I'm seeing a lot of people using the spreadsheet really wisely to figure out percentiles

3) T: I am just noticing from your calculators we got really far. We got to box plots. You're towards the very end which is good.

Zoe also used the *Send/Receive Documents* feature of the Navigator System to share documents that contained data that students analyzed during the lesson. Furthermore, students reduced the data in the spreadsheet file that was sent to their calculators because they wanted to choose the characteristic of an object that would best predict its weight. Zoe sent and received files six times (16.2%), three each, to the students calculators. Finally, Zoe used the login screen of the Navigator System to take the daily attendance twice (5.4%). Once students logged into the system, Zoe could quickly identify who was present and absent from class for that day and then use that information to record her attendance online using her computer. The login screen made taking attendance easier for Zoe.

Vignette 13. Taking attendance using the Navigator System (Observation 9, 10/31/14)

1) T: If you haven't already logged in, I want you to do that now because I'm actually going to show you a couple of nice things on the calculator.
2) T: I should probably do attendance. I guess I could just do that off the board, everyone's logged in anyway.
3) T: See another reason why I love technology, it makes my attendance easier.

As we see from the results and Table 16, the use of the *Live Presenter* allowed students work at their own pace as they became familiar with using the calculator to find probabilities for various questions. Additionally, Zoe gathered information from students regarding these concepts by asking *Quick Poll* questions towards the end of each lesson. Furthermore, Zoe was able to monitor the progress of her students by using the *Screen Capture* feature as students worked during the lesson to reduce and analyze data. She could also quickly *Send/Receive Documents* from each student as an additional way to hold students accountable for completing their work. Finally, the login screen provided an avenue for Zoe to quickly take attendance at the beginning of class.

Summary of Zoe's Navigator Use in the Classroom

The primary use of the Navigator System was to gain insight into the work and thinking of students using three methods that include helping students learn where probability features were located on the calculator and the input information needed to complete the operations using the *Live Presenter*, *gathering information* via *Quick Polls*, and *monitoring student progress* via the *Screen Capture*. These accounted for 29 of the 37 uses of the Navigator System. This suggests that Zoe wanted to make sure that her students could use the calculator to compute the probabilities for given problems so that students could spend more time understanding their answers versus trying to do computations. We see during one lesson, she even makes a statement that after students have learned the formula they are not going to use it, but instead use the calculators to help them with the computation portion of the problem and spend more time analyzing the results.

Vignette 14. Using the calculator to assist with computations involving the binomial distribution (Observation 16, 11/20/14)

1) T: So ladies and gentlemen here is the formula for binomial distribution, I think this is on the next page.
2) T: You are going to write it down and then we are probably never going to use it, but that's because we have calculators and I'll explain my reasoning on this but I feel like I should stop talking so you don't mess up.

3) T: This formula's beautiful.

4) T: This is how they find the exact probability of how many times you will probably be successful.

5) T: Too bad we're never going to use it [the binomial distribution formula]

6) T: Guys, here's the thing.

7) T: My focus is let's find a number and figure out what that number means instead of spending 20 minutes trying to find the number.

8) T: So you guys might have a professor who wants you to work through this problem, but I've noticed a lot of them are retiring and a lot of the new stats professors are embracing technology either using the TI-Nspires or the TI-84s or they'll use this program called R which runs on your computer just like this stuff does or you can even use excel to find it.

9) T: So there's a lot of technology that will find it and most professors are switching over to the technology. Not all of them, but most of them.

10) T: So guys let's use the technology.

Second, Zoe used *Quick Polls* to test students understanding of lesson content by asking them to provide their answers to example problems during instruction. The *Quick Polls* allowed Zoe to ask students questions in which they have to provide a numeric response. By displaying the results, Zoe and the class could assess understanding and use this information to open discussion for how to solve the given example. Finally, the use of the *Screen Capture* allowed Zoe to keep students accountable by monitoring their progress during instruction and using their calculator screen information to engage in discussion with students, as well as provide feedback on their progress. The visual display of information provided access into students' work, which Zoe could use as a spring board to probe more deeply by questioning and discussion. The use of the *Live Presenter* and *Screen Capture* indicate that Zoe likes to be able to see what her students are doing at any given moment while these features are in use. The visual also helps students familiarize themselves with the technology at their pace. Additional results regarding the planning continuum for the *Quick Poll* questions will be shared next.

Navigator Use and the Planning Continuum

Zoe's 37 instances of Navigator use were analyzed using the continuum of unplanned to planned assessments as suggested by Shavelson et al. (2008) to determine if assessments were created prior to or during instruction. Zoe used the *Quick Poll* and *Screen Capture* features of the system as a way to formatively assess her students understanding of statistical concepts during instruction. Although the *Live Presenter*, *Send/Receive Documents*, and login screen were also used by Zoe, these features were not used for formative assessment purposes and thus will not be analyzed using the planning continuum. Therefore, only the 10 *Quick Poll* questions and the 7 *Screen Capture* moments in which students were being assessed will be analyzed using the planning continuum.

There were 10 instances of the *Quick Polls* in use by Zoe over the 17 lessons. All of the *Quick Poll* questions came directly from the lesson notes. Since Zoe taught the statistics course in previous years, she knew which examples she wanted students to work through during instruction and get feedback from students to make sure they understood the mathematical content for the given lesson. All 10 (100%) of her *Quick Poll* questions were *planned-for-interaction*. However, it should be noted that 3/10 *Quick Polls* were taken from the notes displayed on the board and typed in the Navigator System while students worked through the examples during instruction. Although Zoe had planned to give these examples prior to the lesson, she still had to enter the questions into the system before students could receive the *Quick Polls*.

The *Screen Capture* feature of the Navigator System was used to monitor student progress during instruction. This served two purposes. First it allowed the teacher to keep students accountable while working during class. Second, it allowed the teacher to assess where students were at any given moment during instruction. Zoe used the *Screen Capture* feature to *monitor student progress* 6 times during instruction and used the results that students had produced as an opportunity to *lead into discussion* towards the end of class regarding predictions from given data once. The use of the *Screen Capture* was used *to monitor student progress*. Hence, all instances in which the teacher responded to student progress were *on-the-fly* because she didn't plan prior to instruction when she would respond to the progress of the students. A summary of the different question types asked using the *Quick Polls* feature of the Navigator System and the number of questions that were created *on-the-fly*, *planned-for-interaction*, or *embedded-in-the-curriculum* is provided in Table 17 below.

Table 17. Summary of Zoe's assessments and planning continuum

Navigator system feature	Purpose/Question Type	Number of occurrences (percent)	On-the-fly	Planned-for-interaction	Embedded-in-the-curriculum
Quick Polls	Gathering information	10/17 (58.8%)		10/10 (100%)	
Screen Capture	Monitor student progress	6/17 (35.3%)	6/6 (100%)		
	Use screen capture to lead into discussion	1/17 (5.9%)	1/1 (100%)		
Total		17	7	10	0

When *gathering information* from students via *Quick Polls* Zoe always used questions that were *planned-for-interaction*. Again, these questions were created in years prior and were given to students during class as a way to gage their understanding of the statistical concepts students were learning. These questions were created using the built-in expressions and equations template that allowed students to type in their numeric response. Furthermore, Zoe also used the grading feature of the system to highlight the correct answer once results were displayed to the class. During one lesson, students were demonstrating their understanding of permutations as they worked through the following example. Students were asked to determine the number of possible ways to set up an evening television show if there were eight stories that could be televised and three of them could be shown in the given time. Figure 19 shows the question given via the *Quick Poll* and student responses with the correct answer highlighted.

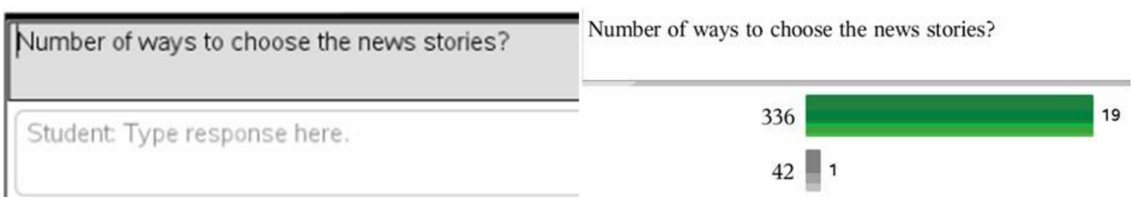


Figure 19. Planned-for-interaction gathering information Quick Poll question.

The *Screen Capture* feature lent itself to *on-the-fly* assessments. Zoe was able to monitor the progress of all students who were logged into the system in one location. The *Screen Capture* option allowed Zoe to react to the pace at which students worked, keep them accountable for getting things done, and provide feedback to help other students know how they were doing with their progress and choice of representation for solving the various math questions they were working on. All seven of Zoe's assessments using the *Screen Capture* feature occurred *on-the-fly* during instruction. Six of those assessments were related to *monitoring the progress* of students during instruction. The vignette below provides evidence for *monitoring student progress* during instruction.

Vignette 15. Using Screen Capture to monitor student progress (Observation 1, 10/10/14)

1) T: I'm curious to see how you are working through problems on your calculator so I'm going to put this up here [*Screen Capture* feature].

2) T: I'm seeing a lot of people using the spreadsheet really wisely to figure out percentiles
3) T: I am just noticing from your calculators we got really far. We got to box plots. That means you're towards the very end which is good.

There was also one instance when Zoe used the *Screen Capture* feature of the Navigator System to *lead into whole class discussion*. During this lesson, students reduced data as they were asked to determine which characteristics would best approximate the weight of a given object. The use of the *Screen Capture* to *lead into discussion* about student choices is provided next in the vignette.

Vignette 16. Using Screen Capture to lead into whole class discussion (Observation 3, 10/21/14)

1) T: I'm kind of studying your calculators [using the *Screen Capture* feature]
2) T: This one right here, her best variable is height, and this one seeds, and this one height, and this on circumference, and this one radius.
3) T: Here's what I get from this
4) T: Most of you found your scatter plot and then some of you started talking about lines of best fit, why did you start talking about lines of best fit?
5) T: What was the goal, what was the goal of these scatter plots?
6) T: What did we want to show with them?
7) T: What represents our weight the best?

Summary of Navigator Use and Planning Continuum

When *gathering information* via *Quick Polls* Zoe used examples that were created prior to the start of the lesson to assess her students. The examples provided a structure for assessment based on the day's content. Since she taught this course before, the questions were already created in the notes and made for an easy transfer to the Navigator System. However, when using the *Screen Capture* feature, Zoe was more likely to comment on student progress and used the students' calculator information displayed through the Navigator System in the moment and commented on items she noticed about their progress or thinking *on-the-fly*. Next, I will consider Zoe's use of real-time data to inform subsequent instruction. This will include her feedback and teaching actions as a result of getting feedback from students and how she used this information to decide what to do next during instruction.

Use of Real-Time Data

There were 17 instances in which Zoe provided feedback to students as a result of using the *Quick Polls* and *Screen Capture*. These 17 instances were categorized into six areas. Then Lee's (2012) levels of feedback were used to code each instance of feedback. A summary of the feedback provided to students, examples, and levels will be presented next.

There were three main ways that Zoe provided feedback to students after they submitted their *Quick Poll* answers. These three forms of feedback were observed 10 times while the Navigator System *Quick Polls* were used. As with the question types, the initial feedback provided to students was used as the unit of analysis to categorize the feedback. Most prominent was for Zoe to *confirm the correct answer* once students submitted their work. This form of feedback occurred 80% (8/10) of the time when Zoe used the Navigator System. If we look more closely at *confirming the correct answer*, we can see three distinct actions. These actions included *moving forward with instruction because the majority of the students answered correctly* (3/10) 30% of the time, *providing a reason for a student's incorrect response* (3/10) 30% of the time, and *asking students to explain their solution* 20% (2/10) of the time. The second type of action that Zoe demonstrated once she received feedback from her students was to *ask her students to provide an explanation* for their solution. This occurred once (10%) while using the *Quick Polls* with students. The third and final way that Zoe used student feedback was to *lead a discussion with students* once (10%) due to a variety of answers submitted. She used the student feedback and discussion to move students towards a correct solution. Zoe led the whole-class discussion as they worked through this particular example.

Zoe also had three types of feedback that she provided to students when using the *Screen Capture* feature. Most prominent was for Zoe to p*rovide a statement to the class indicating progress and completion of the given assignment*. This type of feedback occurred 4/7 (57.1%) times during instruction. The second most common form of feedback that Zoe provided to her students after using the *Screen Capture* feature was to *highlight different representations students used to analyze and answer the questions* such as spreadsheets, box and whisker plots, and graphs. Comments specific to mathematical objects occurred 2/7 (28.6%) times. The last form of feedback, using the results of student work as displayed by the *Screen Capture* to *lead a class discussion*, occurred once (14.3%) during instruction. Table 18 below provides a summary of the types of feedback that Zoe provided to the class once she received feedback from students through the *Quick Polls* and the *Screen Capture* features of the Navigator System.

Table 18. Summary of Zoe's feedback to students

Navigator system feature used	Feedback to students	Number of occurrences (percent)
Quick Polls (10)	Confirm correct answer and move forward with instruction	3/10 (30%)
	Confirm correct answer and provide reason for incorrect student submission	3/10 30%
	Confirm correct answer then ask students to explain their answer	2/10 (20%)
	Ask students to provide justification of solution	1/10 (10%)
	Teacher led discussion with students	1/10 (10%)
Screen Capture (7)	Monitor student progress and completion of assignment	4/7 (57.1%)
	Comment on different representations	2/7 (28.6%)
	Use screen capture to lead into discussion	1/7 (14.3%)

Below are instances of each of the three examples in which Zoe provided feedback to her students during instruction after they had provided her with information through the Navigator System. During one lesson, students were introduced to the mathematical concept of permutations and worked through several examples to support their understanding. For two of the examples, students were given time to work and then asked to submit their answers via *Quick Polls*. The first example asked students to determine how many possible ways eight news stories could be televised if three could air during the shows timeframe. In this example, Zoe *confirms the correct answer and then provides a reason for an incorrect student response*. Figure 20 below represents the *Quick Poll* question given to students and their responses.

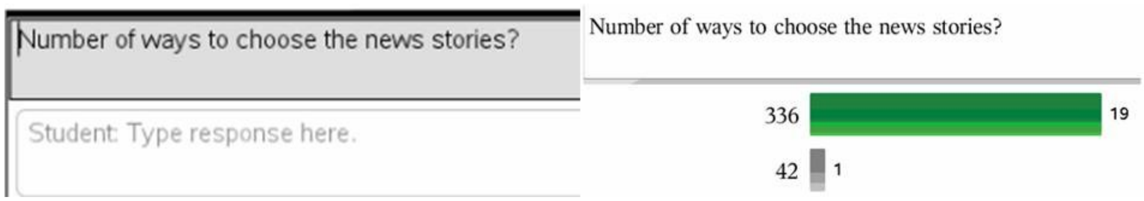


Figure 20. Quick Poll questions given to students with feedback of confirming the correct answer and providing a reason for an answer of 42.

The vignette below represents the feedback Zoe provided to students after reviewing the results of the *Quick Poll* shown in the figure above. This feedback was *confirming the correct answers and providing a reason for an incorrect student response*.

Vignette 17. Examples of feedback provided to students (Observation 9, 10/31/14)

1) T: So guys, it looks like everyone is in.
2) T: We had 336. My guess is someone just answered the next question.
3) T: I feel really good about this, so next question.

We see in the second line Zoe provided a reason why someone responded with 42 as an answer and then proceeds forward with instruction.

For the second example, students were asked to determine how many ways a chairperson and assistant chairperson could be selected for a research project if 7 scientists were available. Students were then asked to submit their responses through a *Quick Poll*. The feedback that followed this example was a *confirmation of the correct answer and then moving forward with instruction*. The following figure and vignette demonstrate the feedback Zoe provided to students to *confirm a correct answer and move forward with instruction*.

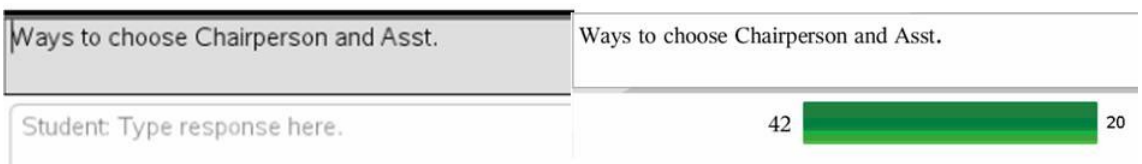


Figure 21. Example of feedback provided by Zoe to move forward with instruction because everyone answered correctly.

Vignette 18. Example of Zoe's feedback to move forward with instruction because everyone answered correctly

1) T: How many ways can we choose one chairperson and one assistant chairperson?
2) T: Don't forget, when you're done hit doc submit.

3) T: Awesome, everybody's in

4) T: Perfect

5) T: So, your homework is, I feel really good, you have 13, 18, 21 and I'm going to pass out new notes.

Here we see that Zoe moved forward because all 20 students correctly answered this question. She did not feel the need to address the example any further and proceeded to assign homework to students.

During a different lesson, Zoe *confirmed the correct answer and asked students to provide an explanation* of how they got their solution. During this lesson, students were learning about the fundamental counting rule. In this particular example, students were asked to determine the number of four digit-ID cards that could be made using the numbers 0, 1, 2, 3, and 4 if repetition of the digits was not allowed. Figure 22 below provides the responses students gave to this *Quick Poll* question.

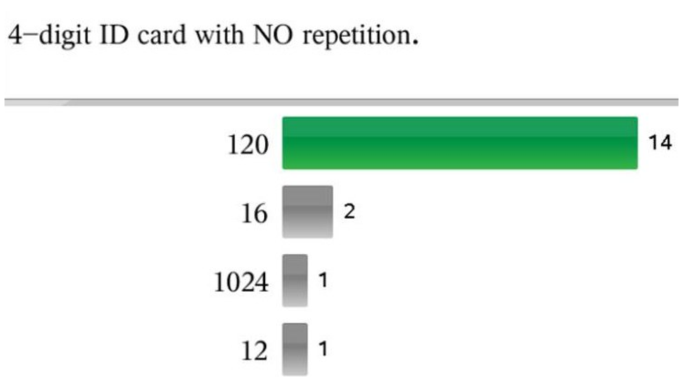


Figure 22. Example of student responses to Quick Poll and feedback asking students to justify the answer of 120.

Zoe initially stated the correct answer was 120, but immediately asked students to explain how they got that answer. Since the majority of the students answered correctly, Zoe wanted a student to explain how they arrived at the correct answer. By having students explain, it would provide an opportunity for those four students who incorrectly answered to better understand how they could have correctly solved this problem. The vignette below shows Zoe's feedback with regards to *following up the correct answer with asking for an explanation from students*.

Vignette 19. Example of confirming correct answer and asking students to justify (Observation 7, 10/29/14)

1) T: A lot of you guys said 120. That was the right answer.
2) T: How did you get 120?
3) FS: Five times four times three times two
4) T: The whole idea is that there are five ways to choose the first one, but then it went down every single time and that's how we got 120. Good.

In addition to confirming correct answers initially, Zoe asked her students to *provide a justification* for their answer once. This occurred during the same lesson in which students learned about the fundamental counting rule and worked through examples dealing with and without repetitions. Students were asked to determine how many four-digit IDs could be created from the digits 0, 1, 2, 3, and 4 if repetition of the numbers was allowed. Zoe initially responded to the students' answers by asking them how they got their answer. Figure 23 below provides the *Quick Poll* question and students' responses. The vignette that follows provides Zoe's feedback to students.

Figure 23. Example Quick Poll question followed by asking for a student justification.

Vignette 20. Example of feedback asking students to explain their solution (Observation 7, 10/29/14)

1) T: A lot of you guys got 625.
2) T: How did we get 625 for this one?
3) FS: We did five times five times five
4) T: Five ways to choose the first number, five ways to choose the second number, five ways to choose the third number equals 625.
5) T: I'm noticing a couple of people go four times four times four times four. Guys why do we use five? I'm using numbers up to four, so why did you guys choose five?
6) SS: Zero

7) T: Cause zero counts as a number, exactly right.

8) T: So those are just a couple of things that I'm noticing.

9) T: Here's what I want you guys to do. Make sure you write down your homework for tonight.

The final way in which Zoe provided feedback to student responses to *Quick Polls* was to use their responses to *lead into whole-class discussion*. This type of feedback occurred once during instruction. During this lesson, students learned about combinations, their differences from permutations, and worked through examples dealing with combinations. Students were permitted to use their calculators for computational purposes if they wished. Students had time to work through the examples and were then given *Quick Poll* questions as a means to collect feedback on their understanding. One such question asked students to determine the number of possibilities to form a committee of three women and two men if there were seven women and five men in the club. Zoe used the student responses to lead them through a discussion of how to solve this problem. Figure 24 below provides the student responses from the *Quick Poll* and then the class discussion that followed after Zoe looked at the students' results.

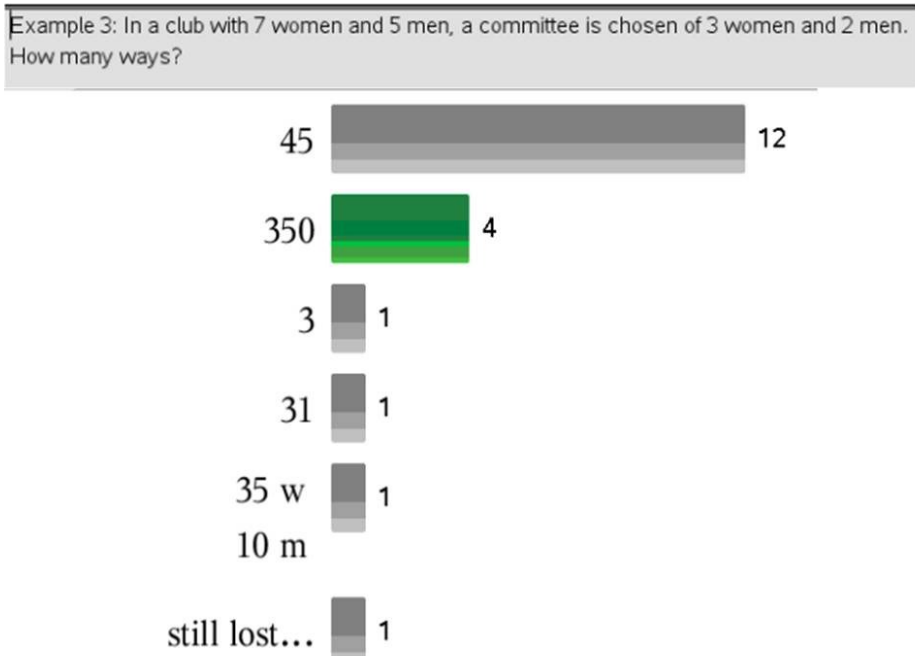


Figure 24. Example of Zoe's feedback to lead a whole class discussion.

Vignette 21. Zoe's feedback to lead a whole class discussion (Observation 10, 11/3/14)

1) T: It looks like we have everyone submitted.
2) T: This is why I like anonymity
3) T: Here's the problem.
4) T: This is a good one to talk about because we got some different opinions.
5) T: In a club that has seven women and five men you want to choose a committee that has three women on it and two men.
6) T: So when you guys did seven choose three, which both of you got 45, I can tell that you did this part right.
7) T: When you got seven choose three, what number did that give you?

8) SS: 35

9) T: 35

10) T: And when you do five choose two what does that give you?

11) SS: 10

12) T: 10

13) T: Now, the key to this is when you have a committee with men and women on it for every one woman that you choose you have to talk about all the ways you can choose another woman and another man to be on the committee.

14) T: This is a tree diagram idea.

15) T: When we've done tree diagrams what do we do with the number? Multiply or add them?

16) SS: Multiple

17) T: We multiply and that's why the numbers should be multiplied.

Zoe chose to *lead a class discussion* to help students understand how they could solve this problem because only 25% of the students correctly answered this question. Based on the results students provided, Zoe could see the need to have a discussion regarding combinations and counting rules to achieve the correct solution. Specifically, she wanted to make sure students understood when they needed to multiply the combinations together versus adding and why. Next, the feedback that Zoe provided students when using the *Screen Capture* feature of the Navigator System will be provided.

Examples of Zoe's feedback to students when using the *Screen Capture* feature were broken down into three categories. The first two were a result of *monitoring student progress* during instruction. Zoe would either *make a statement regarding the progress of students* while they worked in groups on their assignment to help keep everyone moving at a pace that would allow them to finish relatively at the same time and hold them accountable to doing so. This feedback occurred 4/7 (57.1%) times during instruction. The second was for Zoe to *monitor and highlight instances of multiple representations* that students were using to let them know these were good things to be using to help answer their questions. Zoe provided this feedback twice (28.6%) while using the *Screen Capture* feature. The third category of feedback was for Zoe to *engage in a whole class discussion* based on what she saw on the students' calculators. This form of feedback occurred once (14.3%) during instruction. The first vignette below supports Zoe's use of feedback in which she indicated student progress during instruction and their use of multiple representations to help them answer the questions.

Vignette 22. Example of monitoring and providing feedback on student progress (Observation 1, 10/10/14)

1) T: I'm curious to see how you are working through problems on your calculator so I'm going to put this up here [*Screen Capture* feature].
2) T: I'm seeing a lot of people using the spreadsheet really wisely to figure out percentiles

3) T: I am just noticing from your calculators we got really far. We got to box plots. That means you're towards the very end, which is good.

The second line provides students with indication that using the spreadsheets to help find percentiles is a good use of that representation. The third line supports indication on student progress.

Zoe also used the information from the screens of the students graphing calculators that were displayed through the *Screen Capture* feature to *lead into a class discussion*. During this lesson, students worked on an activity to determine which attribute of an object would best predict its weight. Zoe noticed that different groups considered different attributes to determine the objects weight and wanted to engage the class in discussion about using scatter plots as a means to support their choice of attribute. The next vignette supports Zoe's feedback that led into a class discussion.

Vignette 23. Example of using Screen Capture to lead into whole class discussion (Observation 3, 10/21/14)

1) T: I'm kind of studying your calculators [using the *Screen Capture* feature]
2) T: This one right here, her best variable is height, and this one seeds, and this one height, and this on circumference, and this one radius.
3) FS: I said height. I was just messed around on that one.
4) T: Here's what I want to get from this

5) T: Most of you found your scatter plot and then some of you started talking about lines of best fit, why did you start talking about lines of best fit?
6) T: What was the goal, what was the goal of these scatter plots?
7) T: What did we want to show with them?
8) FS: What represents weight the best
9) T: What represented our weight the best.
10) T: As the weight went up, what did we want our other data to do?
11) SS: Go up.
12) T: Go up.
13) T: What's true about the dots and the line if it's a better indicator of the weight?
14) MS: Can you repeat that
15) T: Maybe I can say it differently
16) T: Look at the dots. Look at the line.
17) MS: Okay
18) T: If it's a good indicator what's true about the dots?
19) SS: They are close to the line.
20) MS: They're grouped.
21) T: They're close to the line
22) T: What do you mean by group?
23) MS: The dots are in one little area. There are no outliers.
24) T: They're all in one area, okay. No really outliers.

25) T: And are we close to the line or farther away from it?

26) SS: Close

27) T: We should be close to our line, hopefully.

28) T: So did you arrive at what you thought was a good indicator of weight?

29) SS: Yeah, yes.

30) T: What did you guys think?

31) MS: Height

32) T: What did you guys think?

33) FS: Height

34) T: Is it possible that maybe there is more than one right answer?

35) SS: Yeap, yeah.

36) FS: Actually we said two things

37) T: And then you were able to confirm which one you thought

38) T: Alright, here's what I'd like to do. I want to see if I can collect your data.

Zoe used the *Screen Capture* feature and the information displayed by the students as a spring board for *leading them into a discussion* regarding their choice for determining which characteristic can be used to best predict the weight of the object. Next, the results of coding each type of feedback using Lee's (2012) feedback level framework will be presented.

Lee's (2012) three levels of feedback are *evaluative/normative*, *corrective/verification* or *elaborative/facilitative*. Of the 17 times that Zoe provided feedback to students after a *Quick Poll* or using the *Screen Capture* feature, level one feedback was given 35.3% (6/17) of the time. Level one feedback focused on monitoring student progress with regards to completion of the assignment, comments on different representations that students used to help answer questions, and using the results of student work as displayed by the screen capture to lead a class discussion. The most prominent form of feedback provided to students was level two, or *corrective/verification* feedback. Level two feedback occurred 58.8% (10/17) of the time during instruction and included verification of the correct answer, providing a specific comment indicating that using spread sheets to determine percentiles was correct, and asking students to justify their solution. *Elaborative/facilitative*, or level three feedback was provided once (5.9%) during instruction. This one instance occurred when Zoe used the results of a *Quick Poll* to lead a discussion with students regarding how to compute the correct answer and whether to use addition or multiplication with combinations. The categories of feedback that Zoe provided to students during instruction are summarized in

Table 19 according to system feature.

Table 19. Summary of Zoe's feedback levels

System Feature Used	Occurrence	Feedback level	Zoe's Feedback to students	Number of occurrences (percent)
Quick Polls	10	One	None	0%
		Two	Confirm correct answer and move forward with instruction	3/10 (30%)
			Confirm correct answer and provide reason for incorrect student submission	3/10 (30%)
			Confirm correct answer then ask students to explain their answer	2/10 (20%)
			Ask students to provide justification of solution	1/10 (10%)
		Three	Teacher led discussion with students	1/10 (10%)
Screen Capture	7	One	Monitor student progress and completion of assignment	4/7 (57.1%)
			Use screen capture to lead into discussion	1/7 (14.3%)
			Comment on different representations	1/7 (14.3%)
		Two	Comment on different representations	1/7 (14.3%)
		Three	None	0%
Total	17			

Summary of Zoe's Use of Real-Time Data

The type of feedback that Zoe provided to students depended on the system feature used. Student responses from the *Quick Poll* questions were used to inform her instruction and feedback presented to students. The three main ways that Zoe used the real-time data to inform her instruction based on the results from the *Quick Polls* were to provide feedback to *confirm the correct response*, *ask students to provide a justification for their solution*, or *lead a discussion* with students due to a variety of answers submitted that would help them understand how to move towards a correct solution. Ninety percent (9/10) of the feedback provided to students after using the *Quick Polls* was level two or *corrective/verification* feedback. Additionally, 10% of the feedback after *Quick Polls* was *elaborative/facilitative*, or level three feedback. Zoe never provided level one feedback to students when using the *Quick Polls*.

With regards to the *Screen Capture* feature, Zoe also demonstrated three types of feedback that included *providing a statement to the class indicating progress and completion of the given assignment*, *monitoring student progress to highlight different representations* that students were using to analyze and answer questions, and using students *Screen Capture* work to *lead a class discussion*. Level one feedback was most prominent when using the *Screen Capture* feature as this *evaluative/normative* feedback was provided 85.7% (6/7) of the time during instruction. The only time level two feedback was provided when using the *Screen Capture* feature was when Zoe made reference specifically to using spread sheets to help determine percentiles, indicating this was a correct use of the spread sheets to answer the percentile questions. The responses students provided using the *Quick Polls* and through the *Screen Capture* feature were used by Zoe to inform her instruction and the feedback she gave back to students.

Putting it All Together

Zoe demonstrated two main formative assessment processes during the instruction of statistical concepts. The first process emerged while Zoe used the *Live Presenter* and *Quick Poll* features of the Navigator System. This process integrated four of the five key strategies, omitting the first key strategy of clarifying and sharing learning intentions and criteria for success as this was shared verbally with the students. The other four key strategies were evident during Navigator use. Zoe was able to use the Navigator System to elicit evidence of student understanding and learning (KS2) by utilizing the *Quick Polls* feature to send questions and examples for students to work through individually and together (KS4 & 5) and then use the real-time student responses to inform her instruction and provide feedback to her students (KS3). This process was repeated throughout the lesson as time allowed. The ten *Quick Poll* questions that Zoe asked using the Navigator System were *planned-for-interaction* and used to *gather information* from students regarding the statistical concepts being learned. Zoe would in turn display the real-time student responses to the class and use their solutions to inform her instruction and feedback. Three specific forms of feedback were provided for *Quick Poll* questions which included: 1) a *confirmation of the correct answer*, 2) asking students to *provide a justification* for their solution, and 3) Zoe using the responses to *lead a discussion* with her students. The confirmation of correct answers and asking students to provide a justification for their solution were *corrective/verification*, or level two feedback and using the responses to lead a discussion with students was *elaborative/facilitative* or level three feedback. As time allowed, this process would repeat for additional examples.

The second formative assessment process occurred when Zoe used the *Screen Capture* feature of the Navigator System. Similar to the first formative assessment process, key strategy one was shared with students verbally. The second process incorporated key strategies two, three and four. During this formative assessment process, Zoe would begin class by sending a file to the students' graphing calculator. Then students would be given their task, activity, or example to work through (KS2) and the teacher would use the *Screen Capture* feature to monitor student progress (KS3) and encourage them to work together (KS4). There were seven instances of *Screen Capture* use to monitor student progress during instruction. While monitoring student progress via the *Screen Capture* feature, Zoe provided *on-the-fly* feedback to students by *monitoring progress and providing a statement to the class indicating class completion of the given assignment or highlighting different representations* that students were using the analyze and answer questions; and using students *Screen Capture* work to *lead a class discussion*. Feedback provided as a result of monitoring student progress was *evaluative/normative* or level one feedback. The exception was one instance when Zoe provided specific reference regarding the use of spread sheets to find percentiles. This feedback indicated a correct use of the spread sheets and was level two or *corrective/verification* feedback. No level three feedback occurred when using the *Screen Capture* feature. Prior to the conclusion of the lesson, Zoe would recollect files from students' graphing calculators via the Navigator System. Table 20 below reflects the system features Zoe used, the question type or purpose, the planning continuum, feedback and level provided to students. The question types represent key strategy two of the formative assessment framework and feedback represents key strategy three.

Table 20. Summary of Zoe's question types, planning continuum, feedback and level provided to students

Navigator system feature	Purpose/Question Type	Planning continuum	Feedback and level	Occurrence (percent)
Quick Polls	Gathering information (10)	Planned-for-interaction	Confirm correct L2	8/10 (80%)
			Ask students to provide justification L2	1/10 (10%)
			Teacher led discussion with students L3	1/10 (10%)
Screen Capture	Monitor student progress (6)	On-the-fly	Monitor progress L1	4/6 (66.7%)
			Different representations L1	1/6 (16.7%)
			Different representations L2	1/6 (16.7%)
	Use screen capture to lead into discussion (1)	On-the-fly	Use screen capture to lead into discussion L1	1/1 (100%)

All *Quick Poll* questions were *planned-for-interaction* and were given to gather information from students regarding the mathematical concepts being learned for the day's lesson. When following up on student responses, Zoe *confirmed the correct* *answer*, asked students to *provide a justification*, and Zoe *led discussions* with students. Level two and three feedback was provided to students after review the *Quick Poll* results. Alternatively, Zoe used the *Screen Capture* feature *on-the-fly* to *monitor student progress* or use the information on the students' screens to *lead them into a discussion*. This feedback was primarily *evaluative/normative* or level one feedback. The Navigator System allowed for the collection and display of student responses so that Zoe could provide feedback and use the real-time data to inform her instruction. These actions became the heart of Zoe's formative assessment practices as she gathered information from students via *Quick Polls* as a way to elicit evidence of student understanding and learning (KS2), and she used the real-time student responses collected and displayed by the system to inform her instruction and feedback she provided back to students (KS3). Similarly, the *Screen Capture* feature allowed her to *monitor student progress* and *provide feedback that informed students on class completion*, how they might go about solving the given tasks and activities, and using that information to *lead a class discussion*. The use of the *Quick Polls*, *Live Presenter*, and *Screen Capture* accounted for 29 of the 37 instances in which the Navigator System was used during instruction and helped to shape her formative assessment processes during instruction of Statistical concepts.

Chapter 6: The Case of Dan

Chapter 6 explores the case of Dan. This will include background information regarding Dan's teaching experience, the evolution of technology within his classroom to support the teaching and learning of mathematics, and a description of the classes that were observed in which the data came from. Following the introductory material and information about Dan, his process of formative assessment when using the TI-Nspire Navigator System will be presented followed by a closer look at the key strategies present during the use of the technology. Second, Dan's use of the technology as a formative assessment tool, including the system features used and purpose will be shared. Third, Dan's use of real-time data and the feedback he provided to students will be provided. To begin, I share Dan's background and educational information.

At the time of this study, Dan had taught secondary mathematics within one Midwestern state school district for 13 years. He earned a bachelor's degree in Mathematics, a Master of Arts in Education and was certified to teach mathematics to students in grades 7-12. Dan worked in an urban district that was characterized by his state department of education as high student poverty and average student population. Dan incorporated the TI-Navigator System into his instruction over the past six years. His classroom was equipped with a set of 30 TI-Nspire graphing calculators. Students could use calculators during instruction, but were not permitted to take them outside the classroom.

The technology in Dan’s classroom had evolved over 13 years. When he first began teaching in his district, there were three computers in the classroom, one for the teacher and two for student use. The teacher’s computer could connect to the classroom television and be used to present information to students. However, due to the small screen size, this was seldom used. Instead, Dan used an overhead project and the TI-Viewscreen that sat on top the overhead and could project the screen of the TI-83 graphing calculator for students to see. Then, when his district acquired one classroom set of TI-84’s and the corresponding TI-Navigator System he was selected to receive the system for use in his classroom. Dan used this earlier version of the Navigator System for four years. Then SMART Boards were introduced into the district during his tenth year of teaching and he has used them for the past three years. In addition to this technology upgrade, TI-SmartView Emulator software was available for use during mathematics instruction. During this time, a transition from TI-83 to TI-84 graphing calculators also occurred. In Algebra II, students are required to purchase a TI-84, however very few students purchase their own calculator (Initial Teacher Interview 2/20/14). Through a promotional program with Texas Instruments, the district was able to trade classroom sets of TI-84 graphing calculators and their Navigator Systems in exchange for an equivalent number of classroom sets of TI-Nspire graphing calculators and TI-Nspire Navigator Systems. As a result of this exchange, this is Dan’s second year of using the TI-Nspire and Navigator System with students. However, this change came with reservations and those concerns about transferring already made documents from the older version to the newer version were realized upon initial use. Hence, Dan spent time recreating documents and quizzes to use with the TI-Nspire Navigator System. The only reason he switched to the new system was because it was wireless (Initial Teacher Interview, 2/20/14). Next, I will share details regarding Dan's 17 Algebra II lessons that were observed.

Classroom Observations

I had the opportunity to observe Dan teach 17 Algebra II lessons that were 49 minutes in length during the spring of 2014. The majority of the students enrolled in this course were seniors. The course content during the observations included topics of solving logarithmic and exponential equations, rules of logarithms, sequences, and series.

During the classroom observations I focused on Dan's use of the TI-Nspire Navigator System to identify his formative assessment process as supported by the technology. This included identifying the key strategies of formative assessment that were present during instruction while the Navigator System was in use, Dan's process of formative assessment, the system features used, purpose, and Dan's use of real-time data and feedback provided to students. There were 86 instances of the Navigator System in use during 15 of the 17 lessons that I observed. The results reported here are representative of those 86 instances. Next, I will focus on the key strategies of formative assessment that occurred during Dan's instruction while the TI-Nspire Navigator System was in use and describe his process of formative assessment using the technology.

The Process of Formative Assessment

The five key strategies of formative assessment include: 1) clarifying and sharing learning intentions and criteria for success, 2) engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning, 3) providing feedback that moves learners forward, 4) activating students as instructional resources for one another, and 5) activating students as the owners of their own learning (Black & Wiliam, 2009). This framework was used to code each of the 17 classroom observations as a means to identify which of the key strategies were present during instruction when the TI-Nspire Navigator System was in use. Key strategies that were present during instruction, but not when the technology was in use are also noted below. Next I will describe the presence of each key strategy in Dan's formative assessment process when using the Navigator System.

Dan used the Navigator System in 15 of the 17 lessons that I observed. In 13 of those lessons, he shared a statement with students at the beginning of class that provided an indication of what was going to occur during the lesson. One such example of sharing the learning intentions with students at the beginning of class came from a lesson in which students were given a series of numbers and asked to write each series using sigma [summation] notation. Dan proceeded to share a statement with students by stating, "Today we're being asked to write things in sigma notation" (Observation 11, 5/5/14). Although the learning intentions were shared with students, they were simply statements of what was going to be covered during the lesson and were shared verbally by Dan. Since the learning intentions were not shared through the technology, key strategy one does not appear in Dan's formative assessment process at the beginning of instruction. However, there were four lessons in which Dan quantified the criteria for success after completing notes, but prior to sending students the practice document by verbally indicating that 100% was the expected grade by the end of class. Statements such as, "You have all period to get 100%" (Observation 4, 3/19/14), "You definitely should be able to knock this out and get a 100. You have plenty of time for three problems." (Observation 5, 4/1/14), "Number five is a bonus problem. You won't get 100 percent unless you do it, but I'm going to not count it, so a ninety-some percent is going to count as 100." (Observation 16, 5/13/14), and "You have all period to get 100% on this review" (Observation 17, 5/14/14) were indication to students of the quantified criteria for success. Even though the criteria for success of 100% was shared verbally, because it provided students with specific information on their performance, key strategy one was included in Dan's formative assessment process after completing class notes and prior to sending the practice document. By verbally providing students with the quantifiable criteria for success in 24% of the observations, students knew the expectations prior to starting their practice problems. Furthermore, the criterion for success was shared just prior to sending students the practice document, hence starting the second portion of his formative assessment process. Next, the classroom discussions, questions and tasks that Dan used to elicit evidence of student understanding and learning will be shared.

The second key strategy is engineering effective classroom discussions, questions, and learning tasks that elicit evidence of student understanding and learning. Dan followed a regimented routine during typical instruction that included collecting the previous night's homework at the beginning of class, covering examples and notes, and then providing time at the end of the period for students to work on similar examples before the end of class. Students were expected to have all questions correct before the end of class. The Navigator System was used to help inform students and the teacher of their grade, which questions were correct and incorrect, and progress through the practice document relative to the time remaining in class.

Dan created documents using the TI-Nspire Navigator Teacher Software. The number of questions in each practice document depended on the material being covered. Review documents tended to have more practice questions then a typical practice document. Three types of questions were used with the documents. These included expressions and equations, multiple choice, and the use of an image to enter the index and formula for summation notation. Figure 25 below provides an example of a question involving an image. In this example, students had to input the index start and finish values and the corresponding formula for a given series.

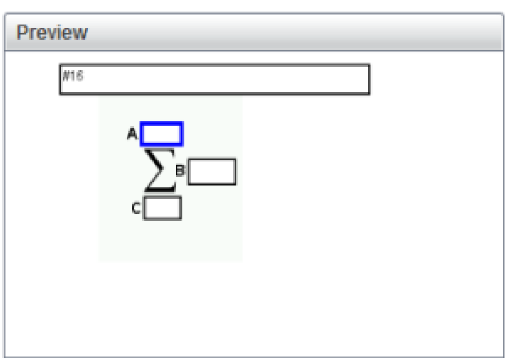


Figure 25. Example question given to students involving an image.

The majority of the questions asked students to input a numeric response as a means to *gather information* from students regarding their ability to correctly answer questions on the day's topic. These questions were created using the built-in expressions and equations question type. Dan also took advantage of the automatic grading option for each question by entering the correct answer and providing a tolerance for answers that varied slightly due to approximations as needed. In instances in which multiple choice questions were given, zero tolerance was used because students were either right or wrong. For numeric responses, a tolerance of +/- 1/10 or +/- 1/100 was typically used. The purpose for using the documents feature was because it allowed for multiple questions to be graded by the Navigator System as well as displayed correct (one) and incorrect (zero) answers so students could monitor their progress and see which questions they had completed correctly and incorrectly. Furthermore, Dan could retain a digital copy of the student responses for each question and their grades. Additional details regarding the use of documents will be discussed in more detail in subsequent sections of this chapter. Next, an overview of the feedback that Dan provided to students will be shared.

The third key strategy of formative assessment is providing feedback that moves learners forward. In this section, an overview of the feedback that Dan provided to his students will be shared. A more in depth description of the feedback provided to students will be shared in the use of real-time data section of this chapter. Nine different forms of feedback were observed during the latter portion of the lesson when students received the practice document to work on during class. The feedback students received included 1) an *emphasis on their grade*, 2) *checking student progress*, 3) *informing students which* *questions they had correct and incorrect*, 4) *suggesting that a student find a partner to collaborate with*, 5) the *amount of time remaining to work or submit the file*, 6) *praise*, 7) *location of a mistake and a hint or cue for direction*, 8) *announcing a change to the test date*, and 9) *asking a student to identify which portion of a three part question was incorrect*. The majority of the feedback that Dan provided to students was *evaluative/normative*, level one feedback (Lee, 2012). However, by asking students to identify the specific questions they had correct or incorrect, he provided level 2 feedback, or *corrective/verification* feedback to students. When Dan stated the location of the mistake in a problem and provided a hint or cue for direction, he provided level 3 or *facilitative/elaborative* feedback to students.

Activating students as instructional resources for one another is the fourth key strategy of the formative assessment framework. As part of his classroom routine, Dan did not mind if students worked together because during the end of class, he would float around the classroom to answer student questions as they arose. There were times when he was unavailable to help other students who had questions, so he encouraged them to work together and get additional support from one another (Initial Teacher Interview, 2/20/14). The routines established at the beginning of the school year were observed during instruction as students moved desks and worked together to answer the practice questions and submit their answers using the TI-Nspire graphing calculators (Observation 2, 3/4/14; Observation 4, 3/19/14; Observation 10, 4/8/14; Observation 17, 5/14/14).

Dan also wanted students to seek assistance from their peers during instruction. As students worked on their practice questions, Dan would encourage students to get support from their peers by making comments such as “you need to find a friend, see if they can explain to you what’s going on with what you are missing” or “Did you ask every single person around you?” (Observation 6, 4/2/14). These collaborations occurred towards the end of the class period and within the time in which the TI-Nspire Navigator System was used to receive files from students’ calculators to grade and provide feedback to students regarding which questions they answered correctly and incorrectly. However, it should be noted that these comments occurred during a lesson in which students were asked to work individually or with a partner, but were not allowed to ask the teacher and adults in the classroom for assistance.

Dan activated students as instructional resources for one another by permitting students to work together if they chose to during the practice portion of instruction at the end of class. If he did comment, it was to encourage students to use their peers as resources. However, since collaboration was part of Dan’s classroom routine, very few comments suggesting collaboration or getting help from peers were present during the classroom observations. Instead, it was expected that students would work together during the practice portion of the lesson. Next, the final key strategy of the formative assessment framework will be shared next.

Activating students as the owners of their own learning is the final key strategy of the formative assessment framework. This key strategy was observed in seven of the lessons. The main way in which Dan wanted students to be the owners of their own learning was to provide comments that encouraged them to check their work once the practice document was received and graded by the Navigator System. For instance, Dan would say, “we’re going to collect it and you’re going to check and you’re going to work until you have 100%” (Observation 4, 3/19/14), “I recollected, come up and check” (Observation 5, 4/1/14), “If you didn’t get 100, figure out which one’s you missed. Keep working until you get 100.” (Observation 6, 4/2/14), and “The rest of you, try to figure out what you’re missing” (Observation 10, 4/8/14). Dan wanted students to take ownership of their learning. He encouraged this by using the TI-Navigator System in a manner that would support students having the opportunity to submit their work via the calculator, collect the document from the calculator, automatically grade the document and student answers, and then display the results for students to check on the board. A correct answer was indicated by one, an incorrect answer was indicated by zero, and the percent obtained after each collect or retrieval of the document was available to students. Dan activated students as owners of their own learning by telling them the document had been collected, to check their grade, identify what questions they had answered correctly and incorrectly, and to continue to work towards 100%. Next, I will consider how each of the five key strategies helped shape Dan’s formative assessment process.

Dan displayed one distinct formative assessment process when using the TI-Nspire Navigator System. To successfully implement this process, Dan had to create homework and practice documents to go with each lesson. Although Dan had files created for the earlier version of the Navigator System, when he upgraded to the TI-Nspire Navigator System, he had to recreate all his documents. The majority of the documents that were used during the classroom observations had been previously created with the upgraded system and used with Algebra II students. Dan’s formative assessment process when integrating the TI-Nspire Navigator System and use of the documents into instruction is presented below in Figure 26.

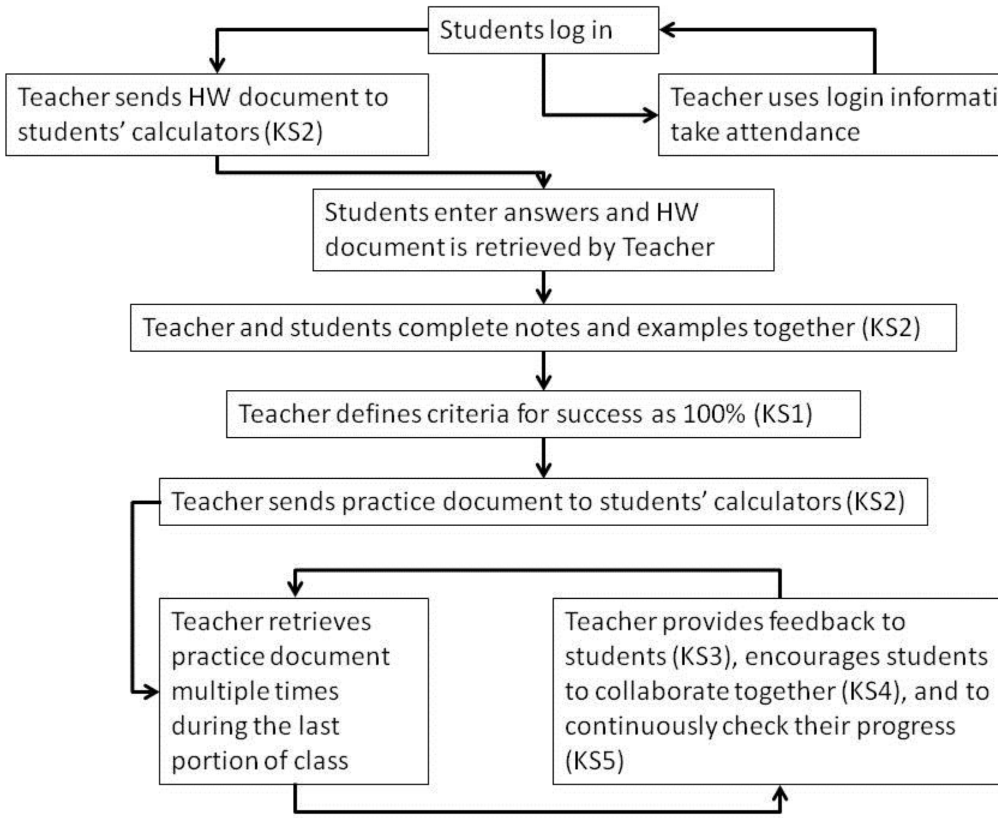


Figure 26. Dan's formative assessment process when using TI-Nspire Navigator System.

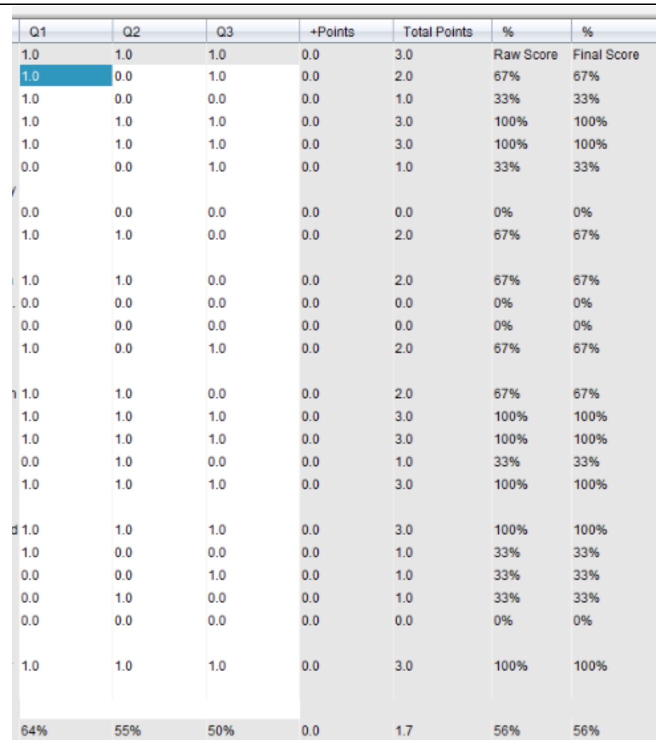
Dan's formative assessment process included key strategies one, two, three, four, and five of the formative assessment framework. The first key strategy (KS1) of sharing learning intentions and criteria for success appeared twice during the lesson, but was included only once in his formative assessment process. The first was near the beginning of class when Dan verbally shared the learning intentions with students regarding the day's focus by stating, “Today we’re going to talk about some of the ways log rules work” (Observation 5, 4/1/14), or “Today we’re being asked to write things in sigma notation” (Observation 11, 5/5/14). Since these learning intentions were shared with student verbally by Dan and not via the Navigator System they do not appear at the beginning of Dan’s formative assessment process. However, the second instance of KS1 appeared after the completion of class notes and examples. The first key strategy appears in Dan’s formative assessment process prior to sending students the practice file because stating the criteria for success of 100% provided students with a quantifiable goal to reach by the end of the period. Additionally, the criteria were shared in 24% of the lessons.

Class typically began with students logging into their graphing calculators so they could receive documents for the day’s lesson. These documents included one for the previous day’s homework and one for the current day’s practice. Dan also utilized the log in process as a way to verify student attendance. For those students who were slow to log in, Dan would ask if they were present. If a student was present and responded, he would ask them to “please log in” (Observation 12, 5/6/14). If they were absent, no response was given or another student might say they were not there. There were three ways in which Dan engineered effective classroom discussions, questions, and learning tasks to elicit evidence of student understanding and learning (KS2). The first was to submit a homework document to students at the beginning of class where they entered their numeric responses and then the teacher received the file back from students, making sure to delete it from their calculators. Dan stated that, “when I collect [receive a document] I always delete it because I don’t want it to linger there and kids to put it on later”

(Observation 5, 4/1/14). It was during this initial sequence of sending the homework document to the students' graphing calculators that Dan elicits evidence of student understanding regarding last night's mathematical content. However, Dan, "never shows them their homework score for time sake" (Observation 5, 4/1/14), but does quickly look at the results prior to starting the current day's lesson. Upon collecting the homework assignment through the Navigator System, the class worked together through class notes and examples before starting their practice document for the day. The second way that Dan elicited evidence of student understanding and learning occurred during the notes and examples portion of the lesson. During this time, the class and teacher worked together to solve examples related to the day's topic. Then, students were given time to work on practice problems, similar to those completed in the notes, which was the third instance during instruction when Dan elicited evidence of student understanding and learning. Once the notes and examples were completed, students were given time to work through practice problems. During this segment of the lesson, students worked individually or together to answer the questions in the calculator on the practice document sent through the Navigator System. Dan often waited for students to ask him to collect [receive] the practice document. He stated that, "so as they ask me to, I will do the collect and I'll collect" (Observation 4, 3/19/14). During this time, it is expected that student would collaborate (KS4) and check their grade, determine which questions they had correct and incorrect, and redo those incorrect questions to work towards a 100% for the day's practice (KS5). Dan also provided *evaluative/normative*, *corrective/verification* and *facilitative/elaborative* feedback (Lee, 2012) between each collect (KS3). Feedback provided to students included: 1) an *emphasis on their grade*, 2) *checking student progress*, 3) *informing students which questions they had correct and incorrect,* 4) *suggesting that a student find a partner to collaborate with*, 5) the *amount of time remaining to work or submit the file*, 6) *praise*, 7) *location of a mistake and a hint or cue for direction*, 8) *announcing a change to the test date*, and 9) *asking a student to identify which portion of a three part question was incorrect*. This loop informed both the teacher and students on their progress and informed the feedback Dan provided to his students. A more in depth look of the homework and practice documents, purpose, and Dan's use of the real-time data will occur in three subsequent sections of this chapter. Next, I will focus on the practice documents, the class responses after collecting the homework document and Dan's use of the real-time data to provide feedback to students as displayed during his formative assessment process.

Table 21 below provides a description of the mathematical concepts in the practice documents that Dan asked using the TI-Nspire Navigator System to elicit evidence of student understanding and learning (KS2), the student grades and answer summary as organized and displayed by the system to the class, and Dan's feedback to students after reviewing the real-time data during instruction (KS3) from selected lessons. These lessons were chosen because the student data was available.

Table 21. A selection of Dan's formative assessment questions, student responses, and feedback using Send/Receive Documents

Content in practice document sent to student graphing calculators	Real-time data shared with class after receiving practice document	Dan’s feedback to students after reviewing practice document results
Rules of logarithms, simplifying, expanding, and evaluating logarithmic expressions (3 questions)		Collect 1 – Grade 7S at 100% 5S at 67% 6S at 33% 4S at 0%

Q1	Q2	Q3	+Points	Total Points	%	%
1.0	1.0	1.0	0.0	3.0	Raw Score	Final Score
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	0.0	0.0	0.0	1.0	33%	33%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	0.0	1.0	0.0	1.0	33%	33%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	0.0	0.0	2.0	67%	67%
0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	1.0	0.0	0.0	1.0	33%	33%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	0.0	0.0	1.0	33%	33%
0.0	0.0	1.0	0.0	1.0	33%	33%
0.0	1.0	0.0	0.0	1.0	33%	33%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	3.0	100%	100%
64%	55%	50%	0.0	1.7	56%	56%

Continued

Table 21 continued

Collect 2 - Grade

12S at 100%
6S at 67%
2S at 33%
2S at 0%

Q1	Q2	Q3	+Points	Total Points	%	%
1.0	1.0	1.0	0.0	3.0	Raw Score	Final Score
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	1.0	1.0	0.0	2.0	67%	67%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	0.0	0.0	0.0	1.0	33%	33%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	0.0	0.0	1.0	33%	33%
1.0	1.0	1.0	0.0	3.0	100%	100%
86%	73%	68%	0.0	2.3	76%	76%

Continued

Table 21 continued

Q1	Q2	Q3	+Points	Total Points	%	%
1.0	1.0	1.0	0.0	3.0	Raw Score	Final Score
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	0.0	0.0	1.0	33%	33%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	0.0	0.0	0.0	1.0	33%	33%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
91%	73%	73%	0.0	2.4	79%	79%

Collect 3 – Asking students to check which questions they had correct and incorrect

14S at 100%
4S at 67%
2S at 33%
2S at 0%

Continued

Table 21 continued

Q1	Q2	Q3	+Points	Total Points	%	%
1.0	1.0	1.0	0.0	3.0	Raw Score	Final Score
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	0.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
0.0	0.0	1.0	0.0	1.0	33%	33%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	0.0	1.0	0.0	2.0	67%	67%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
1.0	1.0	1.0	0.0	3.0	100%	100%
91%	82%	91%	0.0	2.6	88%	88%

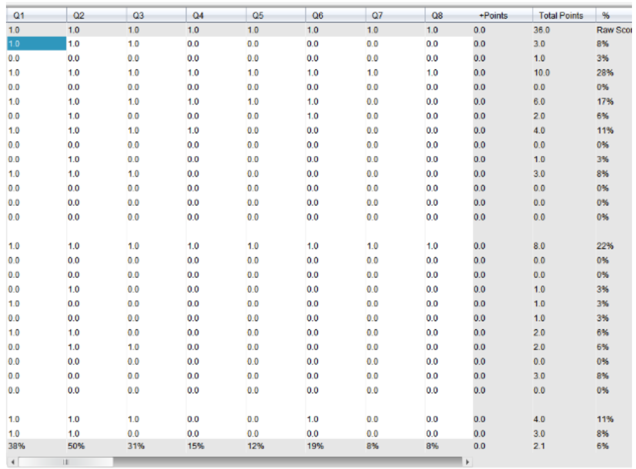
Collect 4 – Grade

17S at 100%
3S at 67%
1S at 33%
1S at 0%

Continued

Table 21 continued

Review of rewriting exponential and logarithm equations, evaluating, simplifying, expanding logarithmic expressions using rules of logarithms (21 questions)



Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	36.0	Raw Scor
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	10.0	28%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	6.0	17%
0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	2.0	6%
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	11%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	8.0	22%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%
1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	4.0	11%
1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%
38%	50%	31%	15%	12%	19%	8%	8%	0.0	2.1	6%

Collect 1 – Amount of time remaining to work or submit the file

1S at 28%
25S at or below 22%

184

Continued

Table 21 continued

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	36.0	Raw Score	Final Score
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%	3%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	19.0	53%	53%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	8.0	22%	22%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	17.0	47%	47%
0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	4.0	11%	11%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	9.0	25%	25%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	27.0	75%	75%
1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	6.0	17%	17%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	14%	14%
1.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	5.0	14%	14%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	9.0	25%	25%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%	3%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	9.0	25%	25%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	22%	22%
1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	5.0	14%	14%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	10.0	28%	28%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	9.0	25%	25%
54%	69%	65%	42%	38%	46%	35%	35%	0.0	6.3	18%	18%

Collect 2 – Grade

1S at 75%
1S at 53%
1S at 47%
23S at or below 28%

Continued

Table 21 continued

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	36.0	Raw Score	Final S
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%	3%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	28.0	78%	78%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	10.0	28%	28%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	27.0	75%	75%
0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	7.0	19%	19%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	15.0	42%	42%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%	8%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%	3%
0.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	8.0	22%	22%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	31.0	86%	86%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	10.0	28%	28%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	22%	22%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	12.0	33%	33%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	13.0	36%	36%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	8%	8%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	12.0	33%	33%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6%	6%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3%	3%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	22%	22%
1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	5.0	14%	14%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	14.0	39%	39%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	13.0	36%	36%
58%	77%	73%	46%	46%	50%	42%	42%	0.0	9.2	26%	26%

Collect 3 – Suggesting that a student find a partner to collaborate with

1S at 86%
1S at 78%
1S at 75%
23S at or below 42%

Continued

Table 21 continued

Find the nth term, sum, and write summation notation for arithmetic sequence (3 questions)	(see scores below)	Collect 1-3 no feedback was provided to students Collect 4 – Asking a student to identify which portion of a three part question was incorrect

Q1	Q2	Q3-a	Q3-b	Q3-c
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0
1.0	0.0	1.0	1.0	1.0
1.0	1.0	0.0	1.0	1.0
1.0	1.0	0.0	1.0	1.0
1.0	1.0	1.0	0.0	1.0
1.0	1.0	1.0	1.0	0.0
1.0	1.0	0.0	1.0	1.0
0.0	1.0	1.0	1.0	0.0
1.0	1.0	1.0	0.0	0.0
0.0	1.0	0.0	1.0	1.0
0.0	1.0	0.0	1.0	1.0
1.0	0.0	0.0	0.0	1.0
1.0	0.0	1.0	0.0	0.0
1.0	0.0	0.0	0.0	1.0
1.0	0.0	0.0	0.0	0.0
88%	79%	67%	75%	79%

Continued

Table 21 continued

Find nth term and sum of geometric sequence (2 questions)

Q1	Q2	+Points	Total Points	%	%
1.0	1.0	0.0	2.0	Raw Score	Final Score
1.0	1.0	0.0	2.0	100%	100%
0.0	1.0	0.0	1.0	50%	50%
1.0	1.0	0.0	2.0	100%	100%
1.0	1.0	0.0	2.0	100%	100%
1.0	1.0	0.0	2.0	100%	100%
0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	0.0	2.0	100%	100%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	0.0	2.0	100%	100%
0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	0.0	2.0	100%	100%
1.0	1.0	0.0	2.0	100%	100%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	0.0	2.0	100%	100%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0%	0%
41%	45%	0.0	0.9	43%	43%

Collect 1 – Grade

9S at 100%
1S at 50%
12S at 0%

Continued

Table 21 continued

Applications of series (5 questions)

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	8.0	Raw Score	Final Score
1.0	1.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	4.0	50%	50%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	6.0	75%	75%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	4.0	50%	50%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	2.0	25%	25%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	13%	13%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	13%	13%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	38%	38%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
0.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	4.0	50%	50%
0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	5.0	63%	63%
1.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	3.0	38%	38%
1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	6.0	75%	75%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	38%	38%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	25%	25%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	2.0	25%	25%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	2.0	25%	25%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
46%	50%	46%	0%	8%	54%	54%	17%	0.0	2.8	34%	34%

Collect 1 – Location of a mistake and a hint or cue for direction

5S at 75%
1S at 63%
3S at 50%
16S at 38% or below

Continued

Table 21 continued

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	8.0	Raw Score	Final Sc
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	8.0	100%	100%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.0	6.0	75%	[illegible]
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	75%
1.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	6.0	75%	[illegible]
1.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	5.0	63%	[illegible]
0.0	1.0	1.0	0.0	0.0	1.0	1.0	1.0	0.0	5.0	63%	63%
0.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	4.0	50%	[illegible]
1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	4.0	50%	50%
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	50%	[illegible]
0.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	4.0	50%	50%
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	50%	50%
1.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	3.0	38%	38%
1.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	3.0	38%	38%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	3.0	38%	38%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	2.0	25%	25%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	25%	25%
0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	2.0	25%	25%
0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	25%	25%
0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	13%	13%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
50%	58%	63%	13%	8%	67%	63%	38%	0.0	3.6	45%	45%

Collect 2 – Praise

1S at 100%
5S at 75%
2S at 63%
5S at 50%
11S at 38% or below

Continued

Table 21 continued

Review of arithmetic and geometric sequences and series (14 questions)

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	15.0	71%	71%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	14.0	67%	67%
1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	11.0	52%	52%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	9.0	43%	43%
1.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	7.0	33%	33%
1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	7.0	33%	33%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	24%	24%
0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	5.0	24%	24%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	5.0	24%	24%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	5.0	24%	24%
1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	4.0	19%	19%
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0	19%	19%
1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	3.0	14%	14%
1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	14%	14%
1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	14%	14%
1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	3.0	14%	14%
1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	10%	10%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5%	5%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
77%	55%	59%	41%	18%	50%	14%	32%	0.0	4.8	23%	23%

Collect 1 – Announce a change to the test date

1S at 71%
1S at 67%
1S at 52%
19S at or below 43%

Continued

_ Table 21 continued

Additional day of review for arithmetic and geometric sequences and series (14 questions)

Q13	Q14	Q15	Q16	Q17	Q18	Q19-a	(+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.(0.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.(0.0	20.0	95%	95%
1.0	1.0	1.0	0.0	1.0	1.0	0.0	0.(0.0	18.0	86%	86%
1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.(0.0	16.0	76%	76%
0.0	1.0	0.0	0.0	1.0	1.0	0.0	1.(0.0	11.0	52%	52%
1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	11.0	52%	52%
0.0	1.0	0.0	0.0	1.0	1.0	1.0	1.(0.0	10.0	48%	48%
1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.(0.0	9.0	43%	43%
0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.(0.0	8.0	38%	38%
0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.(0.0	7.0	33%	33%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	7.0	33%	33%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	6.0	29%	29%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	6.0	29%	29%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	4.0	19%	19%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	2.0	10%	10%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.(0.0	0.0	0%	0%
23%	36%	9%	14%	27%	27%	18%	230.0	7.5	35%	35%

Collect 1 – Checking student progress

1S at 95%
1S at 86%
1S at 76%
2S at 52%
17S at or below 48%

Continued

Table 21 continued

Q13	Q14	Q15	Q16	Q17	Q18	Q19-a	(+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1 0.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1 0.0	21.0	100%	100%
1.0	1.0	1.0	1.0	1.0	1.0	0.0	0 0.0	19.0	90%	90%
1.0	1.0	0.0	1.0	1.0	1.0	1.0	1 0.0	17.0	81%	81%
1.0	1.0	0.0	0.0	1.0	1.0	0.0	0 0.0	13.0	62%	62%
0.0	1.0	0.0	0.0	1.0	1.0	1.0	1 0.0	12.0	57%	57%
0.0	1.0	0.0	0.0	1.0	1.0	0.0	1 0.0	11.0	52%	52%
1.0	1.0	0.0	0.0	1.0	1.0	0.0	0 0.0	9.0	43%	43%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0 0.0	9.0	43%	43%
0.0	0.0	0.0	0.0	0.0	0.0	1.0	1 0.0	8.0	38%	38%
0.0	0.0	0.0	1.0	0.0	0.0	0.0	0 0.0	8.0	38%	38%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	7.0	33%	33%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0 0.0	7.0	33%	33%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0 0.0	7.0	33%	33%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0 0.0	6.0	29%	29%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	6.0	29%	29%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0 0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	5.0	24%	24%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	2.0	10%	10%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 0.0	0.0	0%	0%
21%	50%	8%	17%	20%	20%	17%	21 0.0	7.6	36%	36%

Collect 2 – Grade

1S at 100%
1S at 90%
1S at 81%
1S at 62%
1S at 57%
19S at or below 52%

Continued

Table 21 continued

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	15.0	71%	71%
1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	8.0	38%	[illegible]
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	13.0	62%	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	[illegible]
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	13.0	62%	[illegible]
0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	8.0	38%	[illegible]
1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	5.0	24%	[illegible]
1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	19.0	90%	[illegible]
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	5.0	24%	24%
0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	14%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	100%	[illegible]
1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	0.0	18.0	86%	[illegible]
1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	8.0	38%	38%
0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	10.0	48%	48%
1.0	1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	12.0	57%	57%
1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	15.0	71%	71%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5%	5%
1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	13.0	62%	62%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	7.0	33%	33%
1.0	0.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	6.0	29%	29%
1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	9.0	43%	43%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	3.0	14%	14%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	12.0	57%	57%
79%	67%	75%	57%	21%	54%	25%	46%	0.0	9.3	44%	44%

Collect 3 – Grade

1S at 100%
1S at 90%
1S at 86%
2S at 71%
3S at 62%
16S at or below 57%

Continued

Table 21 continued

Q13	Q14	Q15	Q16	Q17	Q18	Q19-a	(+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00.0	21.0	100%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00.0	21.0	100%	100%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00.0	19.0	90%	90%
1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.00.0	17.0	81%	81%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.00.0	17.0	81%	81%
1.0	1.0	0.0	1.0	1.0	1.0	0.0	0.00.0	16.0	76%	[illegible]
0.0	1.0	0.0	0.0	1.0	1.0	1.0	1.00.0	14.0	67%	67%
0.0	1.0	0.0	0.0	1.0	1.0	0.0	1.00.0	14.0	67%	67%
0.0	1.0	0.0	0.0	1.0	1.0	1.0	1.00.0	13.0	62%	[illegible]
1.0	1.0	1.0	0.0	1.0	0.0	0.0	0.00.0	13.0	62%	62%
1.0	1.0	1.0	0.0	1.0	1.0	1.0	1.00.0	12.0	57%	[illegible]
0.0	1.0	0.0	0.0	1.0	1.0	1.0	1.00.0	11.0	52%	[illegible]
0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.00.0	10.0	48%	[illegible]
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.00.0	10.0	48%	[illegible]
1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.00.0	9.0	43%	43%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.00.0	8.0	38%	38%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.00.0	8.0	38%	38%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00.0	8.0	38%	38%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.00.0	7.0	33%	33%
0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.00.0	6.0	29%	29%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00.0	3.0	14%	14%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00.0	1.0	5%	5%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00.0	0.0	0%	0%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00.0	0.0	0%	0%
42%	79%	38%	21%	50%	46%	42%	460.0	10.8	51%	51%

Collect 4 – No feedback provided to students

2S at 100%
1S at 90%
2S at 81%
1S at 76%
18S at or below 67%

Continued

Table 21 continued

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	+Points	Total Points	%	%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	100%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	100%	100%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	21.0	100%	[illegible]
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	17.0	81%	[illegible]
1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0	0.0	17.0	81%	81%
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	17.0	81%	81%
1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	17.0	81%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	16.0	76%	[illegible]
1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	14.0	67%	[illegible]
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	13.0	62%	62%
1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	12.0	57%	[illegible]
0.0	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	12.0	57%	57%
1.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	12.0	57%	[illegible]
0.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	11.0	52%	[illegible]
1.0	0.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	10.0	48%	48%
1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	9.0	43%	43%
1.0	1.0	1.0	0.0	1.0	0.0	1.0	1.0	0.0	8.0	38%	38%
1.0	1.0	1.0	1.0	0.0	1.0	0.0	1.0	0.0	8.0	38%	38%
1.0	1.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	7.0	33%	33%
1.0	0.0	1.0	1.0	0.0	1.0	0.0	0.0	0.0	6.0	29%	29%
0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	14%	14%
0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5%	5%
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	5%	5%
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
79%	67%	83%	71%	33%	63%	38%	54%	0.0	11.4	54%	54%

Collect 5 – Amount of time remaining to work or submit the file

3S at 100%
4S at 81%
1S at 76%
16S at or below 67%

Dan used the real-time data of the collected [received] practice documents to inform the feedback he provided to students throughout the remainder of class. During a post-observation interview I asked Dan what he focused on when the real-time data was displayed. He stated that, "I always look at what's going on at the bottom. And how many are at the bottom. But it really depends on whether they had a lot of time" (Post-observation interview 4/8/14). He was referring to the bottom of the screen in Table 21 because it was an indication of the students who had low grades as the Navigator System sorted class grades from highest percentage to lowest percentage. It should be noted that some students at the bottom may not have entered their answers into the document, but were working. Dan also considered the amount of time students had to work on the practice document to determine whether he needed to spend additional time on the content the following day or if he could move forward with instruction. He also considered which questions were left blank by students because, "a lot of these are wrong because they're blank, so they hadn't got to them" (Post-observation interview 4/8/14). The majority of the feedback that Dan provided to students was *evaluative/normative* or level one feedback. This feedback focused on the student, such as reference to their *grade*, how close they were to 100%, or *checking their progress* and working towards achieving 100% before the class ended. Dan stated that, "I'm always pushing them to check their grade" (Post-observation interview, 4/1/14). Therefore, providing feedback to students pertaining to their grade was consistent to Dan's classroom routine of collecting the practice document, having students determine which questions were correct and incorrect, and then fixing their mistakes before the end of class. In the examples provided above, there were seven instances when Dan made reference to the students' grades. In five of these, more than half of the class was at or below a 60%. For the other two lessons, 12/22 and 14/22 students achieved 100% so Dan was confident the other students could also obtain the 100% and referenced their grade to make sure they continued to work towards that perfect score before the end of class. In two lessons, Dan provided feedback with regards to the *amount of time remaining in class or until the practice document would be recollected*. In one lesson the entire class was at or below a 28% and in the other lesson 16/24 students were at or below a 67%. This feedback could be used by students as a reminder to enter their numeric solutions before the end of class. There were two lessons in which Dan provided feedback after the third collect during each lesson. In the first lesson, after the third collect, Dan provided specific feedback to a student by stating that she "missed the first one" (Observation 5, 4/1/14). In the other lesson, Dan suggested that *a student find a peer to collaborate with* by stating, "You need to find a friend. See if they can explain to you what's going on with what you are missing" (Observation 6, 4/2/14). At the end of one lesson, a male student approached the teacher because he kept getting question three incorrect. After the fourth collect, Dan asked the student to *identify which part of question three was incorrect*. However, the student was unable to do so and they agreed to look at it the next day (Observation 11, 5/5/14). Dan provided *elaborative/facilitative* feedback to students as a result of a combination of helping students while they worked on the application problems for series and collecting the practice document. He let students know that question three asked for the sum as several of them were incorrectly solving the problem (Observation 15, 5/12/14). During this same lesson and after the second collect, Dan *praised* two students for a job well done on the practice document. In a subsequent lesson when reviewing arithmetic and geometric sequences and series, 21/22 students were at or below a 67% after the first collect. Due to the high percentage of students struggling, Dan decided to spend another day reviewing this material. His feedback to students informed them of the *testing date change*. On the second day of review, Dan initially provided feedback to the entire class letting them know their progress on the practice document would be projected shortly by stating that he would "collect the review and then put it up" (Observation 17, 5/14/14).

Dan demonstrated key strategies one, two, three, four, and five of the formative assessment framework when using the Navigator System. The System was used to *Send/Receive* practice documents to students during the latter part of the lesson, which became the questions that Dan used to elicit evidence of student thinking and understanding (KS2). It was upon receiving the files back that Dan was able to provide feedback (KS3) to students and to encourage them to take ownership of their learning (KS5). As students worked to complete the practice document they were allowed to collaborate with other peers (KS4). The primary feedback provided to students after receiving, or collecting, the practice document was focused on their *grade* as a percentage to determine if they met the criteria for success of 100% (KS1) before leaving class that day. The system features used, purpose, and feedback provided to students for Dan's formative assessment process are summarized in Table 22 below.

Table 22. Summary of Dan's system features, question types, and feedback provided to students

Navigator system feature	Purpose	Feedback and Feedback Level	Occurrence (Percentage)
Send/Receive homework document	Gathering information	None	NA
Send/Receive practice document	Gathering information	Grade L1	12/24 (50%)
		Amount of time remaining to work or submit L1	3/24 (12.5%)
		Asking a student to identify which portion of a three part question was incorrect L1	2/24 (8.3%)
		Checking student progress L1	2/24 (8.3%)
		Praise L1	1/24 (4.2%)
		Location of mistake or hint/cue for direction L3	1/24 (4.2%)
		Announcing a change to the test date L1	1/24 (4.2%)
		Suggesting a student find partner and collaborate L1	1/24 (4.2%)
		Asking a student to identify which portion of a three part question was incorrect L1	1/24 (4.2%)

Summary of Dan's Formative Assessment Process

Dan's formative assessment process when using the TI-Nspire Navigator System utilized all five key strategies of the formative assessment framework. Students began class by logging into the system. Dan used this information to take attendance and send the homework file to students' graphing calculators. Then Dan would receive or collect the homework document and delete it from the calculator so students could not work on the homework and put answers in during instruction. This was the first instance of eliciting evidence of student understanding and learning during instruction (KS2). Students then worked through class notes and examples with Dan which was the second instance of KS2. After completing the notes and examples, Dan would inform students of the number of questions in the practice document and verbally share the criteria for success of achieving 100% on the practice document before the end of class. Then Dan would use the Navigator System to send the practice document to students, allow them to collaborate together, and monitor their progress as needed. This was the third instance of KS2. At the heart of Dan's formative assessment process was the retrieval or collect of the practice document. It was during the latter part of class that Dan provided one of the nine types of feedback to students. There were no discernible patterns to Dan's feedback, except that he focused on scores that were at the bottom of the grade scale and used feedback to encourage students to work towards 100% and take ownership of their learning. Additional details on the feedback provided to students will be shared in a subsequent section of this chapter. Overall, Dan's formative assessment process integrated key strategies one through five of the formative assessment framework. Next, Dan's Navigator use in the classroom, which includes the frequency and purpose for each system feature used, will be considered.

Navigator Use in the Classroom

There were 86 instances of Navigator use during instruction. Dan used the Navigator System to *Send/Receive* homework and practice documents and for students to log in, enter homework, and take attendance. Table 23 below provides a breakdown of the system features used and purpose corresponding to each feature of the Navigator System.

Table 23. Summary of system feature and purpose for Dan

Navigator system feature	Number of times observed (percent)	Purpose	Number of occurrences, (percent)
Log in	21 (24.4%)	Students log in	5/21 (23.8%)
		Students log in and enter homework	6/21 (28.6%)
		Attendance	10/21 (47.6%)
Send/Receive Documents	65 (75.6%)	Send homework document	2/65 (3%)
		Receive homework document	4/65 (6.2%)
		Send practice document	12/65 (18.5%)
		Receive practice document	47/65 (72.3%)
Total	86		

The primary feature of the Navigator System that Dan used was to *Send/Receive Documents*. Dan used this feature 65/86 (75.6%) times during instruction. The two types of documents that he sent/received to/from students' graphing calculators were for homework and practice. The purpose of each document was to gather information from students with respect to the mathematical content being learned from the night before and during the present day's lesson. For Dan's students this included solving logarithmic and exponential equations, rules of logarithms, sequences, and series. It should be noted that Dan was also able to send the homework document prior to the start of class. There were instances when he sent documents that were not visible during the observations. There were two instances 2/65 (3%) in which the homework document was sent by Dan during the lesson. Students were expected to enter their answers within the first few minutes of class. Dan stated, “I’m giving you three minutes to get your homework in” (Observation 12, 5/6/14). This gave students enough time to get their completed work entered and submitted, but not too much time for those who did not complete the homework a chance to finish it at the beginning of class and enter answers. The homework document was retrieved 4/65 (6.2%) times during instruction.

Sending and receiving the practice document was an important component to Dan’s teaching. He sent the practice document 12/65 (18.5%) times during instruction and received or collected the document 47/65 (72.3%) times. The practice document was sent after the class had completed the notes and examples pertaining to the day’s lesson. The examples in the practice document were very similar to those in the notes and examples. The purpose for giving the practice document was to make sure students could correctly answer example problems related to the day’s topic. During the initial teacher interview, Dan talked about giving students the last ten minutes of class to work on the practice problems “where they will try to show me that they understood what I was talking about that day” (Initial Teacher Interview, 2/20/14). Furthermore, his goal for students prior to leaving class was to know how they performed on the day’s content. He stated that when students, “walk out of my classroom you know whether you understood today’s material. If you got a 20%, then you need help. If you got 100%, then you’re probably good” (Initial Teacher Interview, 2/20/14). At the heart of the Navigator System use was to receive the practice document. It was during this portion of the lesson when Dan and his students got feedback on their progress regarding the practice problems. Receiving the practice document was utilized 47/65 (72.3%) times during instruction. The homework document was received, or collected, between two and five times each lesson. Upon each collect [receive] of the practice document, the percentage obtained by students and which questions were correct and incorrect were provided. Figure 27 below provides an example of the summary screen available to students after each collect or retrieval of the practice document.

Q1	Q2	Q3	Q4	+Points	Total Points	%	%
1.0	1.0	1.0	1.0	0.0	4.0	Raw Score	Final Score
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
0.0	1.0	1.0	0.0	0.0	2.0	50%	50%
1.0	1.0	1.0	0.0	0.0	3.0	75%	75%
1.0	1.0	1.0	0.0	0.0	3.0	75%	75%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
0.0	1.0	0.0	0.0	0.0	1.0	25%	25%
0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
0.0	1.0	1.0	0.0	0.0	2.0	50%	50%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
1.0	1.0	1.0	0.0	0.0	3.0	75%	75%
1.0	0.0	0.0	1.0	0.0	2.0	50%	50%
0.0	1.0	1.0	1.0	0.0	3.0	75%	75%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
1.0	0.0	1.0	0.0	0.0	2.0	50%	50%
0.0	1.0	1.0	0.0	0.0	2.0	50%	50%
1.0	1.0	1.0	0.0	0.0	3.0	75%	75%
0.0	0.0	0.0	0.0	0.0	0.0	0%	0%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
0.0	1.0	1.0	1.0	0.0	3.0	75%	75%
1.0	1.0	1.0	1.0	0.0	4.0	100%	100%
1.0	1.0	1.0	0.0	0.0	3.0	75%	75%
65%	83%	83%	48%	0.0	2.8	70%	70%

Figure 27. Example scoring summary of the practice document.

The automotive grading feature provided a one for correct answers and a zero for incorrect answers. Students could come up to the board to check which questions they had correct and incorrect as well as see their current percentage for the practice document. As time permitted, students could correct their mistakes and work towards the criteria for success established by Dan of 100% before the end of class. This real-time data also provided Dan and his students with information about individual and class progress and was used to help provide feedback to students.

The second way that Dan used the Navigator System was for log in purposes. There were 21/86 (24.4%) references to logging in. This included references to just logging in 5/21 (23.8%), logging in and entering homework 6/21 (28.6%), and logging in so attendance could be recorded 10/21 (47.6%). Students were asked to log into the System as they entered the classroom on a daily basis. Since this had become a classroom norm, several of the students were in the habit of getting a calculator upon entering the class and logging into the System before being asked to do so. This was observed when one student asked, “Can I log in now?” (Observation 11, 5/5/14) and when another student asked, “Are we not logging in?” (Observation 15, 5/12/14). These students were unsuccessful at logging in initially, so they asked Dan to confirm when they might be able to get logged in. In addition to logging in, students were often asked to, “Put your homework into the calculator” (Observation 5, 4/1/14) or “Go ahead and log in. Get your homework in from last night please” (Observation 12, 5/6/14) to indicate that students needed to enter their numeric solutions into the homework document prior to starting class. Dan also uses the Navigator System “for attendance because I can see quickly who’s here, who’s not, so that’s a convenience thing” (Initial Teacher Interview, 2/20/14). For those students who were not logged in, Dan called their name to verify their presence or not in class. For those students who did respond he asked that they, “login please” (Observation 5, 4/1/14).

By asking students to log into the Navigator System, Dan could take attendance, send the homework document for students to enter their answers, or have them ready to receive documents during the lesson. To gather information from students with regards to the mathematical content being learning, Dan sent and received homework and practice documents during class. By collecting or retrieving the practice document several times during the end of class, Dan and his students could monitor their progress, know which questions they answered correctly and incorrectly and what their overall percentage was compared to the goal of 100%.

Summary of Dan’s Navigator Use in the Classroom

The primary use of the Navigator System was to send and receive homework and practice documents that would provide Dan and his students with information about their understanding of the day’s concepts. The use of the *Send/Receive* feature accounted for 65 of the 86 uses of the Navigator System. This suggests that Dan wanted to encourage students to go back and correct their mistakes and work towards 100% before the end of class and to have an electronic record of student performance overtime by receiving the practice document multiple times. Dan also took advantage of the grading feature within the Navigator System to score student responses in the homework and practice documents. By knowing which questions were correct and incorrect, students could go back and fix their mistakes.

Log in was observed 21 of 86 times during instruction. Once students were logged in to the System, Dan could send and receive documents and take attendance. The convenience of having students log into the System and then using this information to take attendance helped Dan quickly identify who was present and who was absent, but also allowed Dan to get students logged who were present but had failed to do so on their own. The use of student log in was a classroom norm as students routinely entered the class, got a calculator and logged in. For Dan, the ability to send and receive documents and have students log in allowed him to structure his instruction around the use of the Navigator System and to use the real-time data to help students work towards a 100% during class. Hence, student log in and sending and receiving documents were Dan's two primary uses of the Navigator System during instruction. Next, the use of the documents with regards to the planning continuum will be shared.

Navigator Use and Planning Continuum

Dan's 86 instances of Navigator use were analyzed using the continuum of unplanned to planned assessments as suggested by Shavelson et al. (2008) to determine if documents were created prior to or during instruction. Dan used the homework and practice documents to formatively assess his students understanding of mathematical concepts during instruction. Although Dan also had students log into the System, log in and enter homework and taking attendance were not used for formative assessment purposes and will not be analyzed using the planning continuum. Instead, the send/receive homework and practice documents instances will be analyzed with the planning continuum. More specifically, since the same document was sent as received, I will focus on the 2 sent homework documents and the 12 sent practice documents to identify when these documents were created as specified by the planning continuum.

There were 14 instances of sending homework and practice documents over the 17 lessons. Both of the homework documents were *embedded-in-the-curriculum* as the questions students were asked to complete were taken from their textbook. Dan modified the homework document to include multiple choice and numeric responses. Dan used the textbook questions to gather information from students with respect to the math content being learned. Having used the TI-Nspire Navigator System the previous two years, Dan had already created the homework files to send to students graphing calculators. No modifications were necessary to these documents so they were ready to go prior to the start of the lesson.

Dan also sent 12 practice documents to students graphing calculators to check their understanding of the present day's mathematical content. Of these 12 practice documents, three were created *on-the-fly* and nine were *embedded-in-the-curriculum*. One of the documents created *on-the-fly* occurred because, "I don't think I made a file of this last year, so now I get to" (Observation 10, 4/8/14). A second file was created *on-the-fly* to include, "a picture and I can ask them to plug in values on the picture" (Observation 11, 5/5/4) so students could answer a question regarding summation notation. The third document created *on-the-fly* occurred during a lesson in which students worked on application problems for series (Observation 15, 5/12/14). No documents were *planned-*

for-interaction because Dan used textbook questions to create his practice documents. The nine practice documents that were *embedded-in-the-curriculum* were created in a previous year and reused during each of the corresponding lessons during the observations. These practice documents were also used to check students' understanding of the material. A summary of the *Send/Receive Documents* feature of the Navigator System created *on-the-fly*, *planned-for-interaction*, or *embedded-in-the-curriculum* is provided in Table 24 below.

Table 24. Summary of Dan's use of documents and the planning continuum

Navigator System feature	Purpose	Number of occurrences	On-the-fly	Planned-for-interaction	Embedded-in-the-curriculum
Send homework document	Gathering information	2			2 (100%)
Send practice document	Gathering information	12	3 (25%)		9 (75%)

Dan always used homework documents that were *embedded-in-the-curriculum* to gather information from students with respect to the day's mathematical topic. The calculator made files were created using the teacher's software and were based off the textbook questions. In the documents, Dan would use a combination of questions that asked for a numeric response, multiple choice, or used an image and then asked students to enter the index and formula for summation notation. In one lesson, students were learning about the rules of logarithms. During the example and notes, students reviewed the rules of logarithms for the addition of logarithms, subtraction of logarithms, and a logarithm to a power. This knowledge was then used to write expressions involving logarithms as a single log or to expand out the logarithm. Table 25 below provides example questions of the current lessons notes and examples and questions from the practice document and homework document from observations 5 and 6.

Table 25. Example questions from homework, class notes and practice documents

Class notes and examples	Practice Document	Homework Document
Write each expression as a single logarithm. $\log_2(10) + \log_2(6) - \log_2(5)$	Write each expression as a single logarithm. $\log_7(x) + \log_7(y) - \log_7(z)$	Write each expression as a single logarithm. $\log_3(4) + \log_3(y) - \log_3(8x)$

The structure of the example question, the practice question and the homework questions are very similar, with differences only in the numbers used. As a result, students could refer to their class notes and examples to help with both the practice document and homework document questions. When checking for understanding at the end of the class, Dan used practice documents that were created *on-the-fly* and *embedded-in-the-curriculum*. The documents that were created *on-the-fly* were done because no document existed for the lesson or changes needed to be made to an existing file because the problems assigned had been changed. Those documents that were *embedded-in-the-curriculum* were created in years prior and used in corresponding lessons during the current year.

Summary of Navigator Use and Planning Continuum

The primary feature of the Navigator System that Dan integrated into his instruction was the use of documents. He was able to send and receive homework and practice documents to students who were logged into the System. By utilizing the receive feature, Dan could collect a practice document from students multiple times during instruction. Each time he collected, students could come up to the board to view their percentage and which questions they answered correctly and incorrectly. Then students could continue to correct their work until they scored 100%. Of the 14 documents that were sent to students graphing calculators, three were created *on-the-fly* and 11 were *embedded-in-the-curriculum* because the questions included in the document were from the textbook. The only modifications Dan made to the questions were to either provide a multiple choice response, a numeric response, or an image that required students to fill in missing information. Next, I will consider Dan's use of real-time data and how he used the information from the Navigator System to provide feedback to his students.

Use of Real-Time Data

Dan provided feedback to students as a result of receiving or collecting the practice document 47 times during instruction. By collecting the document, Dan had several opportunities to provide feedback to students. There were 24 instances in which Dan provided one of nine different forms of feedback to students. This feedback included 1) an *emphasis on their grade*, 2) *checking student progress*, 3) *informing students which questions they had correct and incorrect*, 4) *suggesting that a student find a partner to collaborate with*, 5) the *amount of time remaining to work or submit the file*, 6) *praise*, 7) *location of a mistake and a hint or cue for direction*, 8) *announcing a change to the test date*, and 9) *asking a student to identify which portion of a three part question was incorrect*. These nine types of feedback were then coded using Lee's (2012) levels of feedback to determine if Dan's feedback was *evaluative/normative*, *corrective/verification* or *elaborative/facilitative*. The initial feedback provided to students was used as the unit of analysis to categorize the feedback. First, the nine types of feedback given to students after receiving or collecting their homework document will be considered. Then the level for each type of feedback will be shared.

Most prominent was for Dan to provide feedback regarding students' *grades*. This form of feedback occurred 50% (12/24) of the time when Dan used the Navigator System. The next most prominent type of feedback was to provide students with information regarding the *amount of time remaining in the class or how long students had before the practice document was going to be collected*. This feedback occurred 12.5% (3/24) of the time during instruction. Feedback to students regarding their *progress on the practice document* was the third type of feedback Dan provided to students. He *checked on student progress* 8.3% (2/24) times during the 17 observations. In addition to *checking on student progress*, Dan *informed students which questions they had correct or incorrect* twice (8.3%). This feedback differed from the former because the comments were specific to correct and incorrect answers whereas the checking on progress was for completion of the entire assignment. The remaining five types of feedback occurred once (4.2%) during instruction. This included *suggesting that a student find a partner and collaborate*, *praise*, *location of a mistake or hint/cue for direction*, *announcing a change* *to the test date,* and *asking a student to identify which portion of a three part question was incorrect*. Table 26 below provides a summary of the types of feedback that Dan provided to the class once he received feedback from students through the practice documents feature of the Navigator System.

Table 26. Summary of Dan's feedback to students

Navigator system feature used	Dan's feedback to students	Number of occurrences (percent)
Receive practice document (24)	Emphasis on grade	12/24 (50%)
	Amount of time remaining to work or submit	3/24 (12.5%)
	Checking student progress	2/24 (8.3%)
	Informing students which questions they had correct and incorrect	2/24 (8.3%)
	Suggesting a student find partner and collaborate	1/24 (4.2%)
	Praise	1/24 (4.2%)
	Location of mistake or hint/cue for direction	1/24 (4.2%)
	Announcing a change to the test date	1/24 (4.2%)
	Asking a student to identify which portion of a three part question was incorrect	1/24 (4/2%)

Below are instances of each of the nine examples in which Dan provided feedback to his students during instruction after they provided him with information through the Navigator System. The most prominent form of feedback was a reference to students' *grades*. Comments such as, "We have a bunch of people without 100's up here. We should be able to get some points today." (Observation 4, 3/19/14), "If you didn't get

100, figure out which one's you missed. Keep working until you get 100" (Observation 6, 4/2/14), and "We got our first 100" (Observation 17, 5/14/14) were shared with students as a way to remind them of the expected criteria for success on the practice document before the end of class and to motivate students to work towards that 100.

Three instances of feedback regarding the *amount of time remaining to work on the practice document or before the file was going to be collected* occurred. The first occurrence was during a lesson in which students reviewed concepts of writing equations in exponential and logarithmic form, evaluating logarithms, writing expressions as single logarithms and expanding logarithms. Students had the majority of the class to work on the review. Towards the end of instruction, Dan provided feedback with regards to the amount of time left to work. He stated that, "you've got about 14 minutes left. This would be a good pacing; I think you should be done with the sheet by now. If you're not, you need to work a little bit quicker," (Observation 6, 4/2/14). The second reference to time occurred during the tenth observation. Due to more notes and examples for solving logarithms dealing with natural log (LN), students had fewer time to work on the practice problems by stating, "Not a lot of time today" (Observation 10, 4/8/14). The final reference with regards to time occurred in a lesson in which students were reviewing for their test on exponential and logarithm equations. This review was a compilation of all material associated with simplifying, evaluating, and solving equations containing exponents and logarithms. The reference to time in this lesson came towards the end of the class to let students know the final collect of the practice document was going to occur. Dan stated that, "We're going to collect here in about five seconds and delete"

(Observation 17, 5/14/14). Students knew they had to finish up and enter any remaining work because the document would be collected and deleted from their calculators.

There were two instances in which Dan provided feedback regarding *student progress*. The first instance occurred in a lesson in which students used guess and check to solve exponential equations prior to learning rules for logarithms. Upon collecting the practice document, Dan asked one female student, “What’s going on? Are you still working? I am very disappointed, you should be working until the bell” (Observation 4, 3/19/14). In this case, the feedback Dan provided was to one student regarding their lack of progress on the practice document. The second instance in which Dan commented on *student progress* was geared towards the entire class to let them know that he would, “collect the review and then put it up” (Observation 17, 5/14/14). Students had asked him to collect the document and he confirmed so students could check their progress.

Twice during instruction Dan provided feedback to students that *informed them which questions they had answered correctly and incorrectly* on the practice document. The first instance of this type of feedback was directed to a student when students were writing logarithmic expressions as a single or expanded logarithm and evaluating exponential and logarithmic expressions. While completing the practice document, Dan told a female student that she, “missed the first one” (Observation 5, 4/1/14). The second instance of *providing feedback regarding which questions a student had correct and incorrect* was also directed to a female student. During this lesson students solved exponential equations using properties of logarithms as the variable was in the exponent.

After collecting the practice document, Dan informed the student that, “it says you have none of them correct” (Observation 7, 4/3/14).

Dan suggested to a student that she *find a partner to collaborate with* during a lesson in which students were reviewing writing equations in exponential and logarithmic form, evaluating logarithms, writing expressions as single logarithms and expanded logarithms. In this particular lesson, students were expected to complete the work individually or with a partner, but without the assistance of the teacher or adult in the classroom because Dan wanted to make sure these ideas were firm in his students heads before they moved onto more challenging material. During this lesson, Dan encouraged the female student to collaborate with another peer by saying, “You need to find a friend. See if they can explain to you what’s going on with what you are missing” (Observation 6, 4/2/14).

The next form of feedback was to *ask a student to identify which portion of a three part question was incorrect*. During this lesson, students were asked to find the nth term, sum, and summation notation of an arithmetic sequence. Each piece corresponded to one part of the question in the practice document. A male student was unsure of why he had question number three incorrect and asked Dan for help. The vignette below is the conversation the two had.

Vignette 24. Dan's feedback to student asking them to identify which portion of a three part question was incorrect

1) MS: It keeps saying I got this wrong, but I know it’s right.

2) T: Which part?

3) T: Which part is wrong?

4) MS: I don’t know, it just said number three is wrong.

5) T: Three what? There’s a, b, and c up there.

We see that Dan was trying to help the student identify specifically which part of question three was incorrect so they can fix it. However, the student was unable to determine which part was incorrect. Both agreed to look into this further the following day.

During the fifteenth observation, Dan provided feedback to *praise* two students for their work as well as inform the class of the *location of their mistake and provide a hint/cue* to provide direction to correct the mistake. During this lesson, students worked on application problems for series. Dan *praised* two students for a, “good job” after collecting the practice document and seeing their grade (Observation 15, 5/12/14). During the same lesson, Dan noticed that several students incorrectly answered one of the questions because they misread it. To help provide direction, Dan provided feedback to the class by stating, “On question three with the reports, they’re asking how many total reports will that person have to write? They’re looking for a sum. They’re looking for a sum on that one. (Observation 15, 5/12/14).

The last form of feedback occurred during the 16th observation. During this lesson, students were reviewing for their exponential and logarithm test that was supposed to occur the following day. After collecting the practice document, Dan noticed low student performance and challenge with the material. As a result of poor student performance, Dan decided to postpone the exam. He then informed the class by stating, "just to let you know, from the feeling in the room, we are deciding that we're going to spend another day reviewing this" (Observation 16, 5/13/14). Next, the level of each type of feedback will be shared as described by the feedback level framework of Lee (2012).

Lee (2012) identified three levels of feedback that included *evaluative/normative*, *corrective/verification* or *elaborative/facilitative*. Of the 24 times that Dan provided feedback to students during instruction, level one feedback was given 87.5% (21/24) of the time during instruction. Level one feedback, or *evaluative/normative* feedback focused on students *grades* with respect to 100%, *how much time remained in the class to work or before a practice document was collected*, *asking students to check their progress*, informing students about a *change to the test day*, informing a female student to *find a peer* to explain the problem to her and collaborate with, *praising* two students for a good job, and asking a male student *to identify which part of question three, a, b, or c, was incorrect*. There were two instances (8.3%) in which Dan provided level two or *corrective/verification* feedback. Both instances were directed to specific students regarding which questions they had incorrect for the day's practice file. Dan provided level three, or *elaborative/facilitative* feedback once (4.2%) to the entire class when he informed them that the question they missed asked for the sum. The level of feedback that Dan provided to students during instruction is summarized in Table 27.

Table 27. Summary of Dan's feedback levels

Feedback level	Dan's Feedback to students	Number of occurrences (percent)
Level one	Emphasis on grade Amount of time remaining to work or submit Checking student progress Announcing a change to the test date Suggesting a student find a partner and collaborate Praise Asking a student to identify which portion of a three part question was incorrect	21/24 (87.5%)
Level two	Asking students to check which questions they had correct and incorrect	2/24 (8.3%)
Level three	Location of mistake or hint/cue for direction	1/24 (4.2%)

Summary of Dan's Use of Real-Time Data

The most prominent type of feedback that Dan provided to students during instruction was *evaluative/normative*. This level one feedback occurred 87.5% of the time and included comments regarding student *grades* as a percentage, the *amount of time remaining in class to work on the practice document or time before the practice document would be collected*, *checking the progress of students* on the practice document, *making a change to the test date* due to poor performance by the class, suggesting that a student *find a peer to collaborate with*, *praising* two students for a job well done, and *asking a student to identify which part of a three part question was incorrect*. Dan also provided feedback that was *corrective/verification* twice during instruction (8.3%). This level two feedback included two instances of *informing two* *students which questions they had incorrect* so they could go back and correct them. There was also one instance (4.2%) of level three feedback provided by Dan. This *elaborative/facilitative* feedback provided students with the *location of their mistake and provided a hint/cue* to correct it. Dan informed students that question three was asking for a sum. Dan used level one, two, and three feedback with students and had nine different types of feedback that he used during instruction. Next, a compilation of Dan's documents, planning continuum, and feedback will be shared.

Putting it All Together

Dan's process of formative assessment integrated all five key strategies of the framework during his instruction. Dan clarified and shared the learning intentions and criteria for success with students at two different times during the lesson (KS1). At the beginning of the lesson he verbally provided statements that informed students of the learning intentions for the day's lesson. Since the learning intentions were shared verbally they were not included in his formative assessment process. However, stating the criteria for success of 100% prior to sending students the practice document was included because it gave a specific goal for students to achieve on their work before leaving class for that day. Hence, key strategy one appeared after the class notes and examples but before Dan sent students the practice document in his formative assessment process. Dan used the TI-Nspire Navigator System to elicit evidence of student understanding and learning (KS2) by sending students homework and practice documents in which they would provide answers to questions. The purpose of each document was to *gather information* from students with respect to the mathematical content being learned. For homework, it would have been content learned the night before, and for practice it would have been content learned during the current day's lesson. Questions in the documents were multiple choice, numeric response, or an image to enter summation notation information. Then Dan would receive, or collect, the documents back from students. The results from the practice documents were reviewed by teacher and student and this information helped inform the feedback Dan gave back to students (KS3) as well as promote ownership among students for their learning (KS5). As students worked on the practice document, they were allowed to collaborate with their peers (KS4). At the heart of the formative assessment process was receiving the practice document multiple times throughout the end of the lesson. By recollecting the document, students could identify which questions they answered correctly and incorrectly and work to fix their mistakes before leaving class for the day. It was expected that they reach 100% before the end of class.

Dan sent two homework documents that were *embedded-in-the-curriculum*, three practice documents that were created *on-the-fly*, and nine practice documents that were *embedded-in-the-curriculum*. Dan used the textbook questions to create similar class notes and examples and used specific questions from the textbook for the *embedded-in-the-curriculum* homework and practice documents. The three practice documents that were created *on-the-fly* happened because Dan did not have a file available to use or send to students. Because he had used the Navigator System for the past two years, he spent the time creating documents in past years and had those electronic documents available to use for the present year.

As Dan received the practice document, he was able to provide nine different types of feedback to students during instruction. Seven of the nine types of feedback were *evaluative/normative*, or level one, and included 1) *emphasis on grade*, 2) *amount of time remaining to work or submit*, 3) *checking on student progress*, 4) *announcing a change to the test date*, 5) *suggesting a student find a partner and collaborate*, 6) *praise*, and 7) *asking a student to identify which portion of a three part question was incorrect*. One form of feedback, *informing students which questions they had correct and incorrect*, was level two or *corrective/verification* feedback. Finally, there was one instance of level three, or *elaborative/facilitative* feedback that Dan provided to students when he identified the *location of their mistake and provided a hint/cue for direction to correct the mistake*. Table 28 below reflects the system features Dan used, the purpose, the planning continuum, and the feedback provided to students. The documents were used to elicit evidence of student understanding and learning, key strategy two, and feedback represents key strategy three of the formative assessment framework.

Table 28. Summary of system feature use, purpose, planning continuum, feedback and levels provided to students by Dan

Navigator system feature	Purpose	Planning continuum	Feedback and Feedback Level	Occurrence (Percentage)
Send/Receive homework document	Gathering information	Embedded-in-the-curriculum (2)	None	NA
Send/Receive practice document	Gathering information	On-the-fly (3)	Amount of time remaining to work or submit L1	1/24 (4.2%)
			Asking a student to identify which portion of a three part question was incorrect L1	1/24 (4.2%)
			Praise L1	1/24 (4.2%)
			Location of mistake or hint/cue for direction L3	1/24 (4.2%)
		Embedded-in-the-curriculum (9)	Grade L1	12/24 (50%)
			Announcing a change to the test date L1	1/24 (4.2%)
			Amount of time remaining to work or submit L1	2/24 (8.3%)
			Checking student progress L1	2/24 (8.3%)
			Suggesting a student find partner and collaborate L1	1/24 (4.2%)
			Asking a student to identify which portion of a three part question was incorrect L1	1/24 (4.2%)
			Asking students to check which questions they had correct and incorrect L2	1/24 (4.2%)

Both homework documents and nine of the practice documents were *embedded-in-the-curriculum*. Dan used the textbook questions in these documents to *gather information* from students regarding the mathematical concepts being learned. Dan did not provide feedback or share the results of the homework document with students, but he did provide feedback upon recollecting the practice documents from students. There were seven different types of feedback that Dan provided to students for practice documents that were *embedded-in-the-curriculum*. Six of the seven forms of feedback were level one, or *evaluative/normative* feedback and one type of feedback was level two, *corrective/verification* feedback. Dan also created three practice documents *on-the-fly* and provided feedback to students upon recollecting these documents as well. Four types of feedback were shared with students when working in *on-the-fly* practice documents that included three types that were *evaluative/normative* and one that was *elaborative/facilitative*. It should be noted that even though three of the practice documents were created *on-the-fly*, the problems still came from the textbook. The documents were either not created in the past or needed to be modified to fit the questions students were answering during the day's lesson. The receiving or collecting of documents was at the heart of Dan's formative assessment process. It was through these documents that he elicited evidence of student understanding and learning (KS2), provided feedback (KS3), encouraged students to work together (KS4) and take ownership of their progress by sharing the results of each collect with the class so students could identify their grade, determine which questions they had correct and incorrect (KS5) and fix errors prior to the end of class. Dan would not have been able to accomplish his formative assessment process and use of real-time data for feedback without the Navigator System's ability to receive documents multiple times over the course of a class.

Chapter 7: Cross-Case Analysis

As discussed in Chapters 1 and 2, the implementation of No Child Left Behind (2001) resulted in a national focus on student achievement in education. However, to improve student achievement, the instructional practices and strategies that teachers use during instruction must be known. Although previous research has shown increases in student achievement for students in Algebra I whose classrooms integrated wireless networked classroom technology, such as the TI-Navigator System, into instruction, the need to determine how the technology was used to result in these increases is still unknown (Pape et al., 2012). Additionally, research specific to teachers' formative assessment processes in classrooms with the TI-Nspire Navigator System and that regarding effective classroom assessment is unclear (Wiliam & Thompson, 2008).

To fill these gaps and contribute to existing research on wireless networked classroom technology, this study provided baseline data on three secondary mathematics teachers' formative assessment processes in classrooms that used the TI-Nspire Navigator System during instruction. Results from interviews, classroom observations, and real-time student data of each teacher and their classroom were presented in chapters 4, 5, and 6. In this chapter, a cross-case analysis of the three secondary mathematics classroom teachers is provided with the intent to answer the following three research questions:

1. What does the process of formative assessment look like in secondary mathematics classrooms that integrate TI-Nspire Navigator System into instruction?
2. How do secondary mathematics teachers use the TI-Nspire Navigator System as a formative assessment tool?
3. How do secondary mathematics teachers use the real-time data collected, organized, and displayed by the TI-Nspire Navigator System?

To address the first research question, the formative assessment process of each teacher was considered as informed by the framework presented by Black and Wiliam (2009). The second research question was addressed using data related to Navigator features used and the planning continuum (Shavelson et al., 2008). The third research question was addressed using the specific real-time data and feedback provided to students and using the feedback levels framework presented by Lee (2012). Next, comparisons of the processes of formative assessment are considered.

The Process of Formative Assessment

In this section, the three teachers' processes of formative assessment will be compared and contrasted as a means to address the question: *What does the process of formative assessment look like in secondary mathematics classrooms that integrate TI-Nspire Navigator System into instruction?* To address this question, the key strategies that appeared in all three processes are discussed. Then, similarities and differences across the processes will be considered. To begin, the key strategies will be considered.

The overarching goal of this study was to determine secondary mathematics teachers' formative assessment processes in classrooms that integrated TI-Nspire Navigator System into instruction. The formative assessment framework as defined by Black and Wiliam (2009) was used as a framework for the analysis. The key strategies of formative assessment were identified during each teacher's classroom observations in which the technology was used and are presented in Table 29. Zoe appears twice in the table because she demonstrated two formative assessment processes during instruction. Zoe QP&LP represents her formative assessment process when using the *Quick Poll* (QP) and *Live Presenter* (LP) features of the system. Zoe SC is representative of her *Screen Capture* (SC) formative assessment process.

Table 29. Key strategies present in each teacher's process of formative assessment

Key Strategy	Description	Present during instruction			
		George	Zoe QP&LP	Zoe SC	Dan
One	Clarifying and sharing learning intentions and criteria for success				X
Two	Engineering effective classroom discussions and other learning tasks that elicit evidence of student understanding and learning	X	X	X	X
Three	Providing feedback that moves learners forward	X	X	X	X
Four	Activating students as instructional resources for one another	X	X	X	X
Five	Activating students as the owners of their own learning		X		X

Key Strategies

Key strategy one (KS1), clarifying and sharing learning intentions and criteria for success, appeared in Dan's formative assessment process. More specifically, Dan shared criteria for success with students after class notes and examples were completed but prior to sending the practice document through the Navigator System. Specifically, he informed students that the criterion for success was 100% on the practice document before leaving class each day. Although he did share this verbally with students, because it quantified success on the assessment, it was included in his formative assessment process. George and Zoe also verbally shared the learning intentions with their students at the beginning of class. However, their learning intentions were statements of what should be accomplished by the end of class. These statements did not include a rubric, exemplary or quality work, or quantifiable information about how students would be assessed (Wiliam, 2007). Instead, the learning intentions were statements of the expected outcomes of what students should be able to do by the end of class. Hence, KS1 was not included in George or Zoe's formative assessment processes.

All three teachers engineered effective classroom discussions and other learning tasks that elicited evidence of student understanding and learning during instruction (KS2). Furthermore, the Navigator System was used as a mechanism to send questions and tasks to students to elicit their understanding. After eliciting evidence of student understanding and learning by asking questions and posing tasks through the Navigator System, the three teachers would ask students to submit their responses, or collect their documents during instruction. Upon receiving this real-time data, the teachers analyzed the responses in the moment and provided feedback to students (KS3). The feedback provided to students will be discussed in more detail when addressing the third research question. However, there was evidence of feedback provided to students by all three teachers during instruction.

The fourth key strategy (KS4) of activating students as instructional resources for one another was observed in all three classrooms. George and Zoe would provide verbal cues to their students to encourage them to work together, or to check their answers with one another. Dan's classroom norms included an expectation that students would work together on practice documents. Dan also provided comments that encouraged students to work with their peers, but not as often as George and Zoe because of his classroom norms. Students adopted this classroom norm as evidenced during classroom observations because they moved desks together during practice work time unprompted.

Activating students as the owners of their own learning (KS5) was evident when Zoe used the Quick Poll and Live Presenter features of the Navigator System and during Dan's lessons. Zoe wanted students to try examples on their own as a means to identify which students understood the concepts and which students struggled. By allowing students to work individually first, students could determine whether or not they understood the concept, then confirm their solutions with a partner, and then reflect on their learning process as needed. Dan's regimented routine of collected, or receiving, practice documents from students during the last segment of class was used to provoke students as owners of their own learning. Dan expected students to check their grade, determine which questions they had correct or incorrect, fix their mistakes and work towards a 100% before leaving class for the day. By making the real-time data available to students, they could take ownership of their learning.

Key strategy one was verbally stated by George and Zoe, but not included in their formative assessment processes due to the lack of assessment specificity for students. Dan did provide quantifiable success criteria resulting in the inclusion of KS1 in his formative assessment process. All three teachers incorporated KS2, 3, and 4 into their instruction while using the Navigator System. Finally, Zoe and Dan included KS5 into their process of formative assessment when using the technology. Next, similarities and differences of the three teachers' formative assessment processes will be shared.

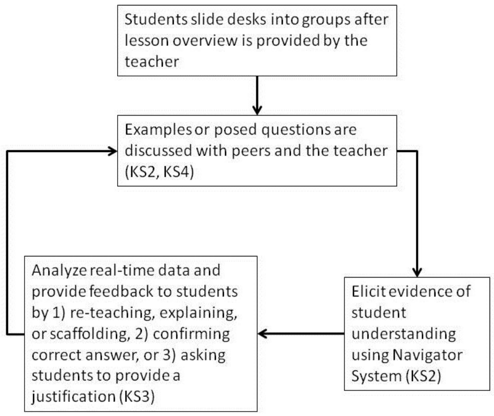
Formative Assessment Process Similarities and Differences

Each teacher displayed their own unique process of formative assessment during instruction. In this section, the similarities and differences of each teacher's formative assessment process are discussed. Each unique process is presented in Table 30. Then similarities are discussed, followed by differences.

Table 30. The process of formative assessment of each teacher

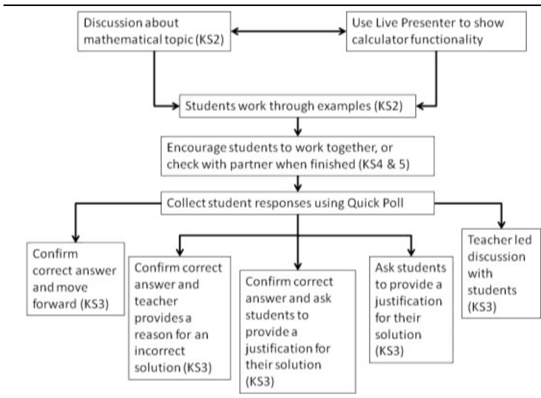
Teacher **Typical Process of Foramtive Assessment**

George

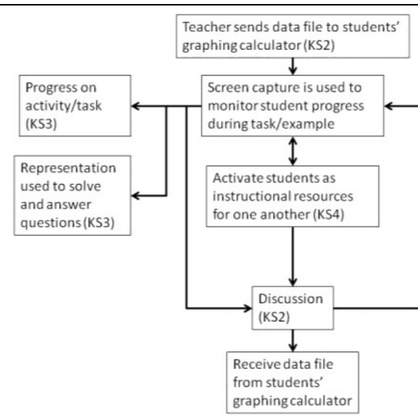


Zoe

QP&LP



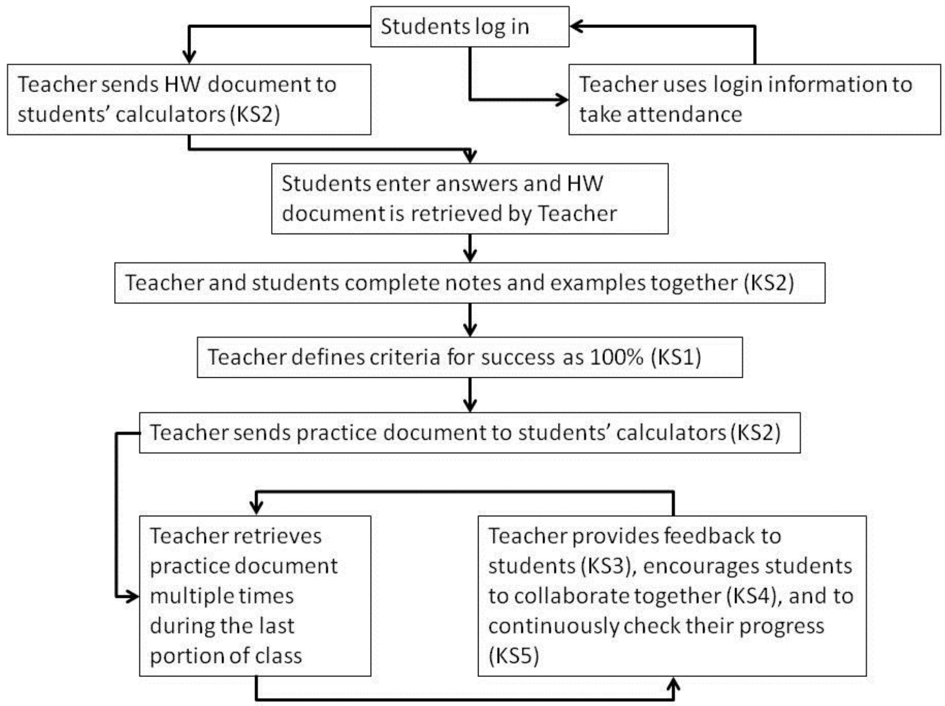
SC



Continued

Table 30 continued

Dan



The first similarity was the use of examples to elicit evidence of student understanding (KS2). All three teachers used the Navigator System as a means to send questions to students during instruction. For George and Zoe this included using the *Quick Polls* and for Dan, sending a homework or practice document to students' graphing calculators. Regardless of feature, students were asked to enter information into the graphing calculator so the results could be retrieved by the teacher using the technology. The second similarity occurred after students submitted their results through the Navigator System. Upon submission, the real-time data was collected and organized for the teacher to analyze. Upon collecting the real-time data, each teacher provided feedback to students during instruction. The type and level of feedback differed for each teacher and will be discussed in more detail when addressing research question three. However, all three teachers would analyze and then respond to the real-time data available to them during instruction. Next, the differences will be discussed.

All three teachers activated students as instructional resources for one another during instruction. What differed was the time during instruction when students were encouraged to collaborate with one another. George encouraged students to collaborate with one another by adapting the classroom environment after sharing the learning targets with students. Typically at the beginning of class, George would ask students to get into their groups causing them to move their desks that were in rows into groups. Zoe promoted collaboration by reminding students to work with one another as they solved problems, or to check their answers with a partner once completed. Dan developed classroom norms that encouraged student collaboration during the practice portion of the lesson that occurred towards the end of class each day. Students acquired this norm as observed during observations as they moved their desks into groups during practice work time unprompted from the teacher. Furthermore, Dan would also provide verbal cues during this time to encourage students to work with peers as needed.

Other differences regarding the key strategies included the sharing of learning intentions and success criteria and activating students as owners of their own learning. All three teachers shared learning intentions with students verbally. However, Dan quantified the criterion for success by informing students that 100% by the end of class was the acceptable level of success. Dan and Zoe differed on how they activated students as owners of their own learning. Dan used the real-time data and feedback to promote self-regulated learning of his students. The real-time data was displayed after each retrieval, or collect, of the practice document for students to observe. Students could come up to the board to identify the specific questions that were answered correctly and incorrectly and to see their percentage. Then students could use this information to take ownership of their learning and reflect on their work to determine why answers were incorrect. Zoe, on the other hand encouraged students to take ownership of their learning by encouraging them to work on examples individually to determine their understanding of the mathematical content being learned. George promoted collaboration in his classroom and therefore did not explicitly activate his students as owners of their own learning during class.

The uniqueness of each formative assessment process was another difference between the three teachers. Each teacher demonstrated a formative assessment process that was unique to their teaching practices and worked in their classrooms with their students. Differences between the three teachers included the structure of the formative assessment process, the system features used and the feedback provided to students. George's process of formative assessment tended to follow a pattern in which students moved their desks into groups to collaborate on questions, students received a question or task through the Navigator System and submitted their responses, then the real-time data was analyzed and feedback followed. This pattern continued for each question posed to students during instruction. Zoe's process of formative assessment when using the *Quick Poll* and *Live Presenter* features differed from George's process during the beginning of instruction. She tended to use the *Live Presenter* feature by randomly selecting a student to operate their calculator that was connected and displayed for the entire class to view and follow along. The use of the *Live Presenter* helped students learn about the functionality of the calculator, to correctly do calculations, and to locate various features of the calculator with respect to statistical concepts being learned during the lesson. The other subtle difference from George's process included encouraging students to collaborate or check their answers with one another after they received their question or task, instead of prior to getting examples. When considering Zoe's formative assessment process when using the *Screen Capture* feature of the system, she tended to also send a data file to students' graphing calculators at the start of class. Students then used this file to work through the given task. Again, students were encouraged to collaborate or check their work with one another after the task had been given. The use of the *Screen Capture* also promoted class discussion between the teacher and students and resulted in a cyclic component to her formative assessment process. The information viewed through the *Screen Capture* helped to promote discussion, and the discussions helped to inform the work of students that was then displayed through the *Screen Capture* for all to see. The majority of the feedback that Zoe provided to her students during both formative assessment processes differed from the feedback George provided to his students.

Dan's process of formative assessment differed from George's and Zoe's with regards to system feature use, structure, and purpose. First, Dan only used documents with his students. His choice for using documents was because there was no limit to the number of questions that could be given to students through a document. Dan preferred to *Send/Receive Documents* over a *Quick Poll* because it allowed him to ask several questions of his students instead of just one at a time. Dan tended to follow a regimented routine when teaching a typical class that included collecting the previous night's homework using the Navigator System and documents, working through class notes and examples with students, giving students the latter portion of class to work through practice questions and collecting student responses via the Navigator System multiple times before the end of class. The purpose for collecting and share the real-time data with students was to promote self-regulated learning. Dan wanted students to use the real-time data to identify incorrect answers, fix their mistakes, and work towards a 100% before leaving class for the day. The latter portion of class resulted in a cyclic formative assessment process in which the real-time data informed the teacher and students of their progress and grades with regards to the success criterion. Additionally, the real-time data helped students identify incorrect answers that could be fixed. As additional data were collected, students could continue to fix their mistakes and work towards 100% before the end of class. Dan also encouraged students to be instructional resources for one another as needed during this time. The feedback that Dan provided to students also differed from the feedback that George and Zoe provided to their students. The differences in feedback will be discussed in more detail when the third research question is addressed later in this chapter.

Summary of Formative Assessment Processes

The process of formative assessment displayed by each teacher was unique. Although no two processes were identical, similarities with respect to KS2 and 3 existed. All three teachers used the Navigator System to send questions to students, collect answers from students, and review the real-time data gathered and organized by the system. All three teachers also provided feedback to students upon reviewing the real-time data. The differences evident during instruction included the actual process of formative assessment enacted by each teacher, when during instruction students were encouraged to be resources for one another (KS4), providing learning intentions versus criteria for success (KS1), and activating students as owners of their own learning (KS5). Next, the three teachers' use of the Navigator System as a formative assessment tool will be considered.

Navigator System as a Formative Assessment Tool

In this section, the second research question is addressed. The frequency codes and descriptive statistics from the individual case studies that included the system features used, question types, and planning continuum were used to address the second research question of: *How do secondary mathematics teachers use the TI-Nspire Navigator System as a formative assessment tool?* Table 31 is a compilation of the system features used, questions types and planning continuum of each teacher as a means to determine how the Navigator System was used as a formative assessment tool. Those system features or question types not used by a teacher were represented by an NA in the table. Then similarities and differences are described.

Table 31. Summary of all three teachers system feature use, question types, and planning continuum

Question Type/Purpose	Occurrence (percentage)	Navigator system feature used	Planning Continuum	George	Zoe	Dan
Gathering information	33/55 (60%)	Quick Polls	On-the-fly	4/9	NA	NA
			Planned-for-interaction	3/9	10/10	NA
			Embedded-in-the-curriculum	2/9	NA	NA
		Send/Receive Documents	On-the-fly	NA	NA	3/14
			Planned-for-interaction	NA	NA	NA
			Embedded-in-the-curriculum	NA	NA	11/14
Questions from HW	7/55 (12.7%)	Quick Polls	Embedded-in-the-curriculum	7/7	NA	NA
Make a prediction	1/55 (1.8%)		Embedded-in-the-curriculum	1/1	NA	NA
Item analysis from quiz or test	2/55 (3.6%)		Planned-for-interaction	2/2	NA	NA
Correct text entry/computation	2/55 (3.6%)		On-the-fly	1/2	NA	NA
			Planned-for-interaction	1/2	NA	NA
Recall of prior knowledge	2/55 (3.6%)		Planned-for-interaction	1/2	NA	NA

Continued

Table 31 continued

			Embedded-in-the-curriculum	1/2	NA	NA
Points earned on assignment	1/55 (1.8%)		Embedded-in-the-curriculum	1/1	NA	NA
Monitor student progress	6/55 (11%)	Screen capture	On-the-fly	NA	6/6	NA
Use sc to lead into discussion	1/55 (1.8%)		On-the-fly	NA	1/1	NA

Navigator System as a Formative Assessment Tool Similarities and Differences

The most prominent way that all three teachers used the Navigator System as a formative assessment tool was to pose questions to *gather information* from students with regards to the mathematical content learned during instruction. Additionally, this was the only question type that all three teachers asked their students. All other questions asked were specific to the teaching styles and classrooms of each teacher and their students. The *gathering information* question occurred 60% of the time during Navigator use and was asked a total of 33/55 times by all three teachers. George *gathered information* 9 times, Zoe 10 times, and Dan 14 times. Differences between the teachers with regards to this question were due to the creation of the question and the system feature used to *gather information*. George and Zoe both used *Quick Polls* whereas Dan used the *Send/Receive Documents* feature to *gather information*. This implies that George and Zoe would *gather information* one question or example at a time whereas Dan would assess his students by asking them multiple questions at once. George and Dan had instances in which the questions they asked were created *on-the-fly*, with the majority of questions created prior to instruction or taken from the textbook or supplemental materials. Zoe always created her *Quick Poll* questions prior to the start of instruction.

Differences within the use of the Navigator System as a formative assessment tool also existed. First, George had the greatest variety of question types/purposes used during instruction to formatively assess his students. This included asking *Quick Poll* questions as a means to gather information from students that included their *questions from homework*, having them *make a prediction*, complete an *item analysis from a quiz or test*, determining if they could *correctly enter the text or do a computation* on the calculator, asking students to *recall prior knowledge*, and *entering points earned on an assignment*. Of the 15 instances in which these questions were asked, just one of the questions occurred *on-the-fly*. The rest were either created prior to instruction by George and were *planned-for-interaction* or were created using the textbook or curriculum resources and were *embedded-in-the-curriculum*. George knew which assessment he wanted to give his student prior to instruction. This was a result of teaching the courses for several years.

Zoe's use of the Navigator System as a formative assessment tool was similar to George when using the *Quick Polls* feature to *gather information* from her students. She took questions from her class notes and created *planned-for-interaction Quick Poll* questions. However, she differed from both George and Dan because she also used the *Screen Capture* feature to formatively assess her students. Zoe specifically used the *Screen Capture* feature to monitor her students' progress during instruction and to use the information displayed on the *Screen Capture* feature to lead into a class discussion. Zoe had to react to the information displayed on the *Screen Capture*; hence all seven instances of these assessments were created *on-the-fly* during instruction.

Dan used the Navigator System to *gather information* from students. Similar to George, the majority of the questions asked were *embedded-in-the-curriculum* as they came directly from the textbook. Dan also had 3/14 documents that were created *on-the-fly* during instruction because the files had not been made in previous years. The major difference between Dan and the other two teachers was with the system feature used. Dan chose to *Send/Receive Documents* to students to check their understanding so more than one question could be asked at a time.

Summary of Navigator System as a Formative Assessment Tool

Each teacher determined which system features would best support their assessments of students and utilized those features and the system as a formative assessment tool. George used the *Quick Poll* feature and the system as a formative assessment tool by asking seven different types of questions that were created *on-the-fly*, *planned-for-interaction*, and *embedded-in-the-curriculum*. Zoe used the Navigator System as a formative assessment tool by using the *Quick Poll* and *Screen Capture* features of the system to *gather information*, *monitor their progress*, and use student work captured by the system to *lead a class discussion*. Her assessments were created *on-the-fly* and *planned-for-interaction*. Finally, Dan chose to use the Navigator System as a formative assessment tool by using the *Send/Receive Documents* feature to *gather information* from students. The majority of his documents were *embedded-in-the-curriculum*. However, there were three instances when files had not been created in previous years and needed to be created *on-the-fly* during instruction. Next, research question three will be addressed by considering the use of real-time data by the three teachers.

Use of Real-Time Data

In this section, the feedback that each teacher provided to students as a result of reviewing the real-time data collected, organized, and displayed by the system is considered. The categories of feedback that emerged from the data as well as the levels of feedback provided to students were used to answer the third research question: *How do secondary mathematics teachers use the real-time data collected, organized, and displayed by TI-Nspire Navigator System?* Table 32 is a summary of the type of feedback provided, system feature used, and the level of feedback as described by Lee (2012). Then a description of the similarities and differences in feedback provided to students is given.

Table 32. Feedback provided to students after reviewing real-time data from the Navigator System

Feedback	Navigator system feature used	Feedback Level	George	Zoe	Dan
Re-teach, explain, scaffold	QP	Three	12/19	1/10	NA
Identify difficulty followed by re-teach, explain, scaffold		Two	1/19	NA	NA
Verify correct answer followed by re-teach, explain, scaffold		Three	1/19	NA	NA
Address differences in answers then re-teach, explain, scaffold		Three	1/19	NA	NA

Continued

Table 32 continued

Student provides justification		Two	2/19	1/10	NA
Confirm correct answer and move forward with instruction		Two	2/19	3/10	NA
Confirm correct answer and provide reason for incorrect student submission		Two	NA	3/10	NA
Confirm correct answer then ask students to explain their answer		Two	NA	2/10	NA
Monitor student progress and completion of assignment	SC	One	NA	4/7	NA
	Send/Receive Documents	One	NA	NA	2/24
Use sc to lead into discussion	SC	One	NA	1/7	NA
Comment on different representations		One	NA	1/7	NA
		Two	NA	1/7	NA
Emphasis on grade	Send/Receive Documents	One	NA	NA	12/24
Amount of time remaining to work or submit		One	NA	NA	3/24
Announce a change to the test date		One	NA	NA	1/24
Suggest a student find a partner and collaborate		One	NA	NA	1/24
Praise		One	NA	NA	1/24
Ask a student to identify which portion of a three part question was incorrect		One	NA	NA	1/24
Ask students to check which questions they had correct and incorrect		Two	NA	NA	2/24
Location of mistake or hint/cue for direction		Three	NA	NA	1/24

Use of Real-Time Data Similarities and Differences

A total of nineteen different uses of the real-time data collected, organized, and displayed by the Navigator System emerged during the analysis of the three secondary mathematics teachers. These nineteen uses represented different forms of feedback that teachers provided to students after analyzing the real-time data. Furthermore, instances of feedback occurred a total of 60 times during instruction for all three teachers. In this section, feedback provided to students by more than one teacher is shared first. Then the level of feedback the teachers provided is discussed, including a consideration of the system feature used.

There were three forms of feedback provided to students that occurred in both George and Zoe's classroom observations. Both teachers used *Quick Poll* questions to elicit evidence of student understanding and analyzed the real-time data during instruction to provide feedback to students. These three forms of feedback included *re-teach, explain, scaffold*, having a *student provide a justification*, and *confirming the correct answer and moving forward with instruction*. Of the 60 instances of feedback provided, the most prominent form of feedback provided by more than one teacher was to *re-teach, explain, or scaffold*. This form of feedback occurred 13/60 (21.7%) times total in George and Zoe's lessons. More specifically, George provided this type of feedback 12 of 19 (63.2%) times to students and Zoe provided this type of feedback once of her 10 (10%) instances of feedback during instruction. The second most prominent type of feedback that showed up across the cases was to *confirm the correct answer and move forward with instruction*. Together, George and Zoe provided this feedback 5/60 (8.3%) times during instruction after reviewing the real-time data from a *Quick Poll* question. If we consider each teacher separately, George confirmed the correct answer and moved forward with instruction 2/19 (10.5%) times and Zoe 3/10 (30%) times. The final form of feedback that was provided by multiple teachers was to *ask a student to provide a justification* for an answer. Again, George and Zoe used the real-time data from a *Quick Poll* question three times (5%) to have a student provide the justification. This form of feedback occurred twice in George's lessons and once is Zoe's lessons. All 16 other forms of feedback were specific to each individual teacher.

In terms of levels of feedback, when George and Zoe would *re-teach, explain, or scaffold*, they provided *elaborative/facilitative* feedback, or level three feedback to students. *Corrective/verification* feedback, or level two feedback was observed when both teachers *confirmed a correct answer and moved forward with instruction* and when asking *students to provide a justification* for an answer. Both teachers tended to provide level two or three feedback when asking *Quick Poll* questions of their students. Next, the level of feedback provided to students is discussed.

There were 29 total instances of feedback provided to students after asking *Quick Poll* questions. The types of feedback provided to students included *re-teach, explain, scaffold*, *identify difficulty followed by re-teach, explain, scaffold*, *verify correct answer followed by re-teach, explain, scaffold*, *address differences in answers then re-teach, explain, scaffold*, *student provides justification*, *confirm correct answer and move forward with instruction*, *confirm correct answer and provide a reason for an incorrect student submission*, and *confirm correct answer then ask students to explain their answer*. When considering the level of feedback provided to students, five of these categories were *corrective/verification*, or level two feedback and three were *elaborative/facilitative*, or level three feedback. Specifically, *identifying difficulty*, *student* *justification*, and the three *confirming correct answer* feedbacks were all *corrective/verification* forms of feedback. All three of the *elaborative/facilitative* feedback dealt with *re-teaching, explaining, and scaffolding*. Both George and Zoe tended to provide level two and three feedback after analyzing real-time data from *Quick Poll* questions.

Zoe was the only teacher to use the *Screen Capture* feature for formative assessment purposes. She used this feature seven times during instruction to *monitor student progress* as they completed the assignment, to *comment on different representations* that were being used to answer questions in the given task, and to use student information from the *Screen Capture* to *lead into class discussion*. Six of the seven instances of feedback that Zoe provided to students when using the *Screen Capture* feature were *evaluative/normative*, or level one feedback. The only instance of level two feedback was when she provided specific comments that informed students of their correct use of representations to answer questions in the given task. Zoe tended to provide *evaluative/normative* feedback to students after analyzing their real-time data through the *Screen Capture* feature.

Dan was the only teacher to provide feedback to students after reviewing information from practice documents that were retrieved by the Navigator System. Dan provided feedback to students 24 times after reviewing practice document results. These 24 instances were broken into nine different categories of feedback. Of these nine categories, seven were *evaluative/normative*, or level one feedback and included *monitoring student progress and completion of the assignment*, *emphasis on grade*, *amount of time remaining to work or submit the document*, *announcing a change to the test date*, *suggesting a student find a partner to collaborate with*, *praise*, and *asking a student to identify which portion of a three part question was incorrect*. These seven categories accounted for 21/24 (87.5%) instances of feedback provided to students. The level two, or *corrective/verification* feedback that Dan provided to his students that asked them to *check which specific questions they had correct and incorrect* occurred twice (8.3%) during instruction. Finally, the one instance (8.3%) of *elaborative/facilitative* feedback that Dan provided to students dealt with the *location of a mistake* several students made with regards to a practice document that he *provided a cue for direction* and what the question was asking. Dan tended to provide *evaluative/normative* feedback that focused on the students' grade in relationship to the success criteria of 100% before the end of class when using the *Send/Receive Documents* feature of the Navigator System.

Summary of Use of Real-Time Data

There were 19 different categories of feedback that teachers provided to students as a result of viewing the real-time data collected, organized, and displayed by the Navigator System. This equated to 60 total instances of feedback provided to students during instruction by all three teachers. George and Zoe tended to provide *corrective/verification* and *elaborative/facilitative* feedback to students after analyzing real-time data from *Quick Poll* questions. Zoe tended to provide *evaluative/normative* feedback to students after analyzing real-time data displayed through the *Screen Capture* feature. Dan also tended to provide *evaluative/normative* feedback to students after analyzing real-time data from the *Send/Receive Document* students worked through during the latter portion of class. There were only three forms of feedback that were used by more than one teacher during instruction. Hence, the feedback provided to students as a result of viewing the real-time data was unique to each teacher and their students.

Chapter Summary

George, Zoe, and Dan each demonstrated their own unique process of formative assessment during instruction. Each process contained key strategies of the formative assessment framework. Specifically, all three teachers integrated key strategies two, three, and four into their instruction. All three teachers used the Navigator System to elicit evidence of student understanding by posing questions to students that were sent via the system to student graphing calculators (KS2). Students then submitted or entered their answers into the calculator and the information was received back to the teacher through the system. Then each teacher analyzed the real-time data and used that information to provide feedback to the class (KS3). As students worked through the questions they were already in pairs or groups to collaborate, or were encouraged to work together or to check their answers with one another (KS4). Dan was the only teacher to implement all five key strategies of the formative assessment framework. The inclusion of the success criteria of 100% on the practice document before leaving class was shared with students just prior to sending the practice document to students. This was included in his formative assessment process because the grade of 100% quantified the goal students needed to achieve before the end of class. Dan’s process of formative assessment also promoted ownership of learning because the real-time data was made available to students during class so they could identify which questions they had correct and incorrect, fix their mistakes, and work towards 100% before the end of class. Dan pushed his students to take ownership of their own learning by making the real-time data available to them during instruction (KS5). Zoe also activated her students as owners of their own learning, but in a different manner. She encouraged students to work individually on example questions three times during instruction to check that each student understood the day's content. The order and structure of the lesson was unique to each teacher. The *Quick Poll*, *Screen Capture*, and *Send/Receive Documents* features were the system features used to elicit evidence of student understanding and became part of each teacher's formative assessment process.

In addition to having their own unique formative assessment process, each teacher also utilized different system features to support their use of the Navigator System as a formative assessment tool. George chose to use the *Quick Poll* feature with seven different types of questions to gather information from students during various parts of the lesson. This included individualized student data in the form of item analysis as well as student answers to questions. Zoe used both the *Quick Poll* and *Screen Capture* features of the Navigator System to *monitor student progress* during instruction and to gather feedback on student understanding of the material. Finally, Dan used the *Send/Receive Documents* feature to collect answers from students several times during the end of instruction to check their ability to correctly answer questions pertaining to the mathematics being learned that day. Each teacher used the Navigator System as a formative assessment tool to send and receive information to and from students. Then this real-time data resulted in various forms and levels of feedback provided to students.

The feedback that teachers provided to students after reviewing the real-time data was also unique to each teacher. There were 19 different categories of feedback observed during instruction which resulted in 60 instances of feedback provided to students. Of the 19 categories, three were observed in both George and Zoe's lessons. This included *re-teach, explain, scaffold*, having a *student provide a justification*, and *confirming the correct answer and moving forward with instruction*. These three forms of feedback were examples of *elaborative/facilitative* feedback and *corrective/verification* feedback that teachers provided to students. George and Zoe tended to provide level two and three feedback to students after reviewing results from the *Quick Poll* questions whereas Zoe and Dan tended to provide level one feedback after reviewing real-time data through the *Screen Capture* and *Send/Receive Documents* features. Each teacher used the real-time data collected, organized, and displayed by the Navigator System to provide feedback to their students throughout instruction. A discussion of the study and conclusions are considered in the next chapter.

Chapter 8: Discussions and Implications

The purpose of this study was to unpack the formative assessment processes of three secondary mathematics teachers who used wireless networked classroom technology, specifically the TI-Nspire Navigator System, during instruction. The results of this study provided baseline data regarding secondary mathematics teachers' formative assessment processes when using technology. The research questions that guided this inquiry included:

1. What does the process of formative assessment look like in secondary mathematics classrooms that integrate the TI-Nspire Navigator System into instruction?
2. How do secondary mathematics teachers use the TI-Nspire Navigator System as a formative assessment tool?
3. How do secondary mathematics teachers use the real-time data collected, organized, and displayed by the TI-Nspire Navigator System?

The remainder of this chapter will include a review of the methodology, summary of results, discussion of results, the development of a formative assessment framework in classrooms with Navigator System technology, limitations, and implications for teaching and research.

Methodology

In this qualitative case study research, the formative assessment processes of three secondary mathematics teachers who integrated wireless networked classroom technology, specifically the TI-Nspire Navigator System, were studied. The results of this study provided a detailed account of the formative assessment processes in each of these classrooms with TI-Nspire Navigator System. This included key strategies of formative assessment present during instruction, the system features used, questions asked, and each teacher’s use of real-time data. Methods used to collect data included a semi-structured initial teacher interview, non-participant classroom observations, semi-structured pre-and post-classroom observation interviews and where applicable, screen capture of the information displayed to students through an LCD project from the teacher’s computer during instruction. All interviews and observations were audio-recorded. Furthermore, observations of an entire unit of instruction occurred when possible to witness potential day to day formative assessment processes as well as those that occurred over the entire unit of instruction. This was possible for Zoe and Dan, but not George. Participation was open to any mathematics teacher who used the TI-Nspire Navigator System with their students during instruction within one Midwestern and adjacent states. The three teachers who participated in this research were chosen because they regularly integrated the specific technology into their instruction. All audio-recorded classroom observations and interviews were transcribed verbatim. Then MAXQDA 11 software was used to code the classroom observations over six passes with respect to the process of formative assessment (Black & Wiliam, 2009), features used, questions asked, planning continuum (Shavelson et al., 2008), feedback provided to students and levels of feedback (Lee, 2012). These five components became part of the conceptual framework used to analyze the data as described in Table 2 found on page 37 of Chapter 2. After completing individual case studies for each of the three participants, a cross-case analysis was conducted to identify similarities and differences between the formative assessment processes of the three teachers. Next, a summary of the results with respect to each research question will be shared.

Summary of Results

George, Zoe, and Dan each demonstrated their own unique process of formative assessment during instruction. Each process contained key strategies of the formative assessment framework. Specifically, all three teachers integrated key strategies two, three, and four into their instruction. All three teachers used the Navigator System to elicit evidence of student understanding by posing questions to students that were sent via the Navigator System to student graphing calculators (KS2). Students then submitted or entered their answers into the calculator and the information was received back to the teacher through the system. Then each teacher analyzed the real-time data and used that information to provide feedback to students (KS3). As students worked through the questions they were already in pairs or groups to collaborate, or were encouraged to work together or to check their answers with one another (KS4). Dan was the only teacher to implement all five key strategies of the formative assessment framework. The inclusion of key strategy one regarding the success criteria of 100% on the practice document before leaving class was shared with students just prior to sending the practice document to their calculators. This was included in his formative assessment process because the grade of 100% quantified the goal students needed to achieve before the end of class. George and Zoe also verbally shared the learning intentions with their students at the beginning of class. Their learning intentions were statements of what should be accomplished by the end of class. However, these statements did not include a rubric, examples of exemplary or quality work, or quantifiable information about how students would be assessed (Wiliam, 2007). Instead, the learning intentions were statements of the expected outcomes of what students should be able to do by the end of class. Hence, KS1 was not included in George or Zoe's formative assessment process. Dan's process of formative assessment also promoted ownership of learning because the real-time data were made available to students during class so they could identify which questions they had correct and incorrect, fix their mistakes, and work towards 100% before the end of class. Dan pushed his students to take ownership of their own learning by making the real-time data available to them during instruction (KS5). Zoe also activated her students as owners of their own learning, but in a different manner. She encouraged students to work individually on example questions three times during instruction to check that each student understood the day's content. The order and structure of the lesson was unique to each teacher. The *Quick Poll*, *Screen Capture,* and *Send/Receive Documents* features were the system features used to elicit evidence of student understanding and became part of each teacher's formative assessment process. Although key strategies two, three, and four emerged in the formative assessment process of each teacher, the manner in which they were implemented during instruction was dependent on the teacher and their style of instruction. Next, a summary of the three teachers' use of the Navigator System as a formative assessment tool will be given.

Each teacher determined which system features would best support their assessments of students and utilized those features and the system as a formative assessment tool. George used the *Quick Poll* feature of the system as a formative assessment tool by asking seven different types of questions that were created *on-the-fly*, *planned-for-interaction*, and *embedded-in-the-curriculum*. These included questions to *gather information*, ask students which *questions they had from their homework* assignment, *make a prediction*, *item analysis from a quiz or test*, determine if students could *correctly enter text or use the calculator* to do a computation, have students *recall prior knowledge*, and have student enter the *number of points earned on an assignment*. Zoe used the Navigator System as a formative assessment tool by using the *Quick Poll* and *Screen Capture* features of the system to *gather information* from students regarding the mathematics content, *monitor their progress*, and use student work captured by the system to *lead a class discussion*. Her assessments were created *on-the-fly* and *planned-for-interaction*. Finally, Dan chose to use the Navigator System as a formative assessment tool by using the *Send/Receive Documents* feature to *gather information* from students with regards to the mathematical content being learned. The majority of his documents were *embedded-in-the-curriculum*. However, there were three instances when files had not been created in previous years and needed to be created *on-the-fly* during instruction. As with the process of formative assessment, each teacher created questions to match their intended assessment needs. Next, a summary of the real-time data used by teachers is provided.

There were 19 different categories of feedback that teachers provided to students as a result of viewing the real-time data collected, organized, and displayed by the Navigator System. This equated to 60 total instances of feedback provided to students during instruction by all three teachers. George and Zoe tended to provide *corrective/verification* and *elaborative/facilitative* feedback to students after analyzing real-time data from *Quick Poll* questions that included *re-teach, explain, scaffold*, *having a student provide a justification*, and *confirming the correct answer and moving forward with instruction*. *Re-teach, explain, scaffold* was the most prominent form of feedback provided to students from more than one teacher and occurred 13/60 (21.7%) times total in George and Zoe's lessons.

Zoe was the only teacher to use the *Screen Capture* feature for formative assessment purposes. She used this feature seven times during instruction to *monitor student progress* as they completed the assignment, to *comment on different representations* that were being used to answer questions in the given task, and to use student information from the *Screen Capture* to *lead into class discussion*. She tended to provide *evaluative/normative* feedback to students after analyzing real-time data displayed through the *Screen Capture* feature, as this level one feedback occurred 6/7 (85.7%) times during instruction.

Dan was the only teacher to use the *Send/Receive Documents* feature of the Navigator System. He also tended to provide *evaluative/normative* feedback to students after analyzing real-time data from the *Send/Receive Document* students worked through during the latter portion or class. There were 24 instances of feedback provided to students after reviewing the documents, broken into nine different categories. Of these nine categories, seven were *evaluative/normative*, or level one feedback and included m*onitoring student progress and completion of the assignment*, *emphasis on grade*, *amount of time remaining to work or submit the document*, *announcing a change to the test date*, *suggesting a student find a partner to collaborate with*, *praise*, and *asking a student to identify which portion of a three part question was incorrect*. These seven categories accounted for 21/24 (87.5%) instances of feedback provided to students. Dan provided feedback that was *corrective/verification* twice and *elaborative/facilitative* once. He tended to provide *evaluative/normative* feedback that focused on the students' *grades* in relationship to the success criteria of 100% before the end of class when using the *Send/Receive Documents* feature of the Navigator System.

There were only three forms of feedback that were used by more than one teacher during instruction. These three forms included *re-teach, explain, scaffold*, having a *student provide a justification*, and *confirming the correct answer and moving forward with instruction*. This left 16 other categories of feedback that were specific to each teacher's classroom. Hence, the feedback provided to students as a result of viewing the real-time data was unique to each teacher and their students. A discussion of these results is provided next.

Discussion of Results

In this section, a discussion of the results in relationship to the three research questions will be provided. First, a discussion of the formative assessment framework in relationship to the key strategies present during the observations will occur. Second, the uses of the Navigator System will be reviewed. Third, the impact of the feedback that teachers' provided will be considered in relationship to the levels of feedback provided. I begin with a discussion of the formative assessment framework.

The Formative Assessment Process

The process of formative assessment begins with key strategy one. This strategy helps the teacher and students identify where the learning is going during instruction as the teacher clarifies the learning intentions and criteria for success for students. However, Wiliam (2007) stated that sharing the learning intentions and criteria for success needs to be more than providing statements to students because, "the words do not have the meaning for the student that they have for the teacher" (p. 1077). One way to help students identify how they will be assessed is to provide rubrics or examples of exemplary work, or have students identify qualities of exemplary work (Wiliam, 2007). However, this raises the question of time in a classroom and what is feasible in terms of providing information to students regarding the assessment details. All three of the teachers in this study shared the learning intentions and criteria for success with students. George and Zoe both shared the learning intentions with students verbally at the start of lesson. Dan also verbally shared the criteria for success with students after class notes and examples but before sending the practice document to student graphing calculators.

Although KS1 was not included in George and Zoe's formative assessment process, the question is raised with regards to the amount of detail needed when stating learning intentions for students and if making a statement of what students should be able to accomplish by the end of class falls into the formative assessment framework. This also raises concern with key strategy one and its importance to the formative assessment process. How much detail and how much time can be spent sharing information with students on a daily basis regarding their assessments? Are there other ways besides providing students with rubrics and examples of work that will allow students to understand the learning intentions and criteria for success in a given lesson? With these questions, the details of implementing key strategy one should be reconsidered.

The second key strategy helps the teacher determine where the learner is right now as the teacher engineers effective classroom discussions and other learning tasks that elicit evidence of student understanding and learning. All three teachers used the Navigator System to elicit evidence of student understanding and learning. However, the feature used to elicit this evidence was specific to each teacher. George used the *Quick Polls* feature, Zoe used both the *Quick Poll* and *Screen Capture* features, and Dan used the *Send/Receive Documents* feature. The different features used to elicit evidence of student understanding and learning seem to be reflective of each teacher and their teaching strategies. George and Dan created the majority of their questions prior to instruction, and Zoe created all of her *Quick Poll* questions before instruction. The creation of questions prior to class indicates that all three teachers considered daily assessments prior to instruction. They thought through the examples and questions they wanted to give students and how they might determine students understanding of the day's material. Their experience teaching these courses in previous years also contributed to their implementation of assessments during instruction.

The types of questions that were sent to students via the Navigator System tended to be procedural in nature (Hiebert & Lefevre, 1986). This is reflected by 60% of questions asked of students were to *gather information* with respect to the mathematical content being learned for the day. It seemed that students were being evaluated on the correctness of their response as the questions given asked them to rehearse procedures (Boaler & Brodie, 2004). The Navigator System provided an avenue for teachers to formatively assess students on algorithms or rules for completing mathematical tasks such as using Heron's formula to find the area of a triangle given three sides, using the Fundamental Counting Rule to determine the total number of combinations and using rules of logarithms to simplify and expand logarithms. The Navigator System tended to provide quick assessments of students' understanding during instruction that helped teachers determine where students were at any given moment. These questions seemed appropriate for the content being learned and the questions asked. However, this raises the question of how to move teachers from asking procedural questions to more conceptual questions using the Navigator System. Using procedural questions may have also impacted the feedback that teachers provided to students during instruction.

Providing feedback to move learners forward was the third key strategy of the formative assessment framework. Although the third research question addresses feedback in greater detail, it is important to note that teachers tended to provide feedback to students that was unique to their classrooms. There were only three of 19 instances in which two teachers, George and Zoe, provided the same type of feedback to their students. The three types of feedback were to *re-teach, explain, scaffold*, having a *student provide a justification*, and *confirming the correct answer and moving forward with instruction*. There were 16 other types of feedback that each teacher provided to their students during instruction. This supports the uniqueness of each formative assessment process and that teachers tended to adopt not only the system features and question types to fit their needs, but also uniquely chose the feedback they provided to their students.

The fourth key strategy of activating students as instructional resources for one another was observed in all three teachers' classrooms. The first way that George integrated KS4 into his instruction was to have students move their desks into groups after the learning intentions and day's outline of class were shared with students. Then, throughout class, George would remind students to work with their group members if they got stuck when working through example questions. Zoe waited until students were given example questions to try before she verbally reminded students to collaborate or to check their answers with one another. She was also the only teacher to ask students when they checked with a partner to defend their position to determine who was correct if their answers did not match. Dan established classroom norms at the beginning of the year that included the expectation that students would collaborate during their time on practice problems towards the end of class (Cobb, Yackel, & Wood, 1995). This was exhibited during the classroom observations as students moved their desks into groups unprompted by the teacher after receiving the practice document. It seemed that all three teachers wanted students to collaborate with one another, but some groups of students were more willing to do this on their own then others. George mentioned that several of his juniors were quiet students and he had to constantly encourage them to work together. Zoe also seemed to remind her students to collaborate with one another often. Dan didn't seem to have to remind students to collaborate with one another, but his students tended to ask him questions just as much as their peers when they struggled with the practice problems. The procedural natural of the questions might have impacted the collaborations between students. If there wasn't much to discuss besides a correct answer, it might have been just as easy for students to work through the example on their own then check their answer with their group members. It seemed that all three teachers wanted their students to be able to check with one another and if there was disagreement, determine who was correct. However, this seemed to be a challenge for students depending on the mathematical content they were learning.

Although this study did not focus specifically on students as they collaborated during instruction, the research on collaborative learning can also support gains in student achievement. These gains have occurred when students work as a group and have responsibilities to contribute to the group. This is different than sitting in a group, working individually and not contributing to the group (Slavin, Hurley, & Chamberlain, 2003). It seemed that because teachers were constantly reminding students to collaborate with one another that collaborative group work may not have been discussed with students at the beginning of the year. However, I did not ask the teachers about their beginning of the year routines. Even though students were in close proximity to one another, it did not guarantee that students collaborated in a manner to increase their achievement. Regardless of the details of the collaborations, this key strategy was evident in all three classrooms.

Activating students as the owners of their own learning is the fifth key strategy of the formative assessment framework. Dan's use of the Navigator System as a formative assessment tool supported the students' ownership of learning the most. He displayed student results after collecting a document during the latter portion of class as a means to get students to identify which questions they answered correctly and incorrectly. Then, as time permitted, students were expected to go back and correct their mistakes as they worked towards 100% before the end of class. In a sense, he promoted self-regulated learning (Zimmerman & Schunk, 1989) because he wanted students to take control of their own learning by identifying incorrect solutions, reworking the problem to determine and fix their mistakes, and then resubmit their results. However, because Dan tended to provide level one feedback that focused on students' grades, instead of focusing students' attention onto the task to encourage students to invest more time with the task, it is unlikely that students self-regulated their learning (Kluger & DeNisi, 1989). Zoe also activated students as owners of their own learning during her *Quick Poll* and *Live Presenter* formative assessment process. There were three questions that Zoe wanted students to answer individually. She wanted students to reflect on their understanding by trying problems on their own and then determining whether they could complete the task or not. It seemed that she promoted metacognition during these three instances because she wanted students to reflect on what they had learned and what they still had questions on (Flavell, 1979).

The key strategies of formative assessment were present in the classroom observations of George, Zoe, and Dan. Each teacher created their own unique process of formative assessment that seemed to match their teaching style and assessment needs of their students that incorporated the different key strategies during instruction. Although there were instances of the key strategies present, it seems that improvements in all five areas could help to strengthen each teacher's process during instruction. With key strategy one, a careful consideration of time taken away from instruction, but providing enough information to students to ensure they understand how they will be assessed needs to occur. The formative assessment framework itself needs to consider how this might be possible in a class period as short as 42 minutes, without taking away valuable instructional time. The types of questions teachers ask when engineering effective classroom discussions and other learning tasks to elicit evidence of student understanding and learning needs to be considered. All three teachers tended to ask procedural questions when using the Navigator System. There are times when these types of questions are appropriate, but that seemed to be the most common type of question asked in each of the classrooms. Teachers should be able to use the Navigator System to elicit evidence of student understanding for more conceptually based questions, gather thoughts or ideas from students and use that information to frame the classroom discussions that follow. However, this may also require a pedagogical shift of teaching practices, which will also take time to accomplish. The feedback that teachers provided may have been impacted by the types of questions that the teachers asked as well. If teachers want to impact their students' achievement, they will need to provide *corrective/verification* or *elaborative/facilitative* feedback to students (Lee, 2012). This level of feedback did occur during instruction, but needs to happen more often to have a positive impact on student understanding. When activating students as instructional resources for one another, teachers need to be familiar with the roles of students when collaborating and working in groups. Just placing students in groups, as all three teachers did, may have minimal benefit to students (Slavin, Hurley, & Chamberlain, 2003). Instead, students need to get into the habit of working together and sharing their ideas, or defending their solutions while in groups. Finally, promoting self-regulation and metacognition during instruction will also help students reflect on their learning and can lead to increased understanding of mathematical content (Zimmerman & Schunk, 1989). All three teachers have touched on the five key strategies, but it seems they could improve the strength of their formative assessment process by tending to some of the concerns raised above.

Navigator System as a Formative Assessment Tool

In this section, the use of the Navigator System as a formative assessment tool will be discussed. The most prominent way that the Navigator System was used as a formative assessment tool was to *gather information* from students regarding their ability to compute answers with respect to the mathematical content being learned. This result is consistent with previous research on the Navigator System (Bellman, Foshay, & Gremillion, 2014; Case & Pape, 2013). Each teacher also used features of the system to meet their assessment needs during instruction. In addition, creativity on the part of

George was evident in his seven different question types asked using the Navigator System during instruction. Not only did he gauge his students' understanding of content being learned for the lesson, he found other uses of the features of the Navigator System to collect information from students with regards to their progress on homework, quizzes, and tests. George adapted the functionality of the technology to fit his needs (Kerr, 2004). Specifically, in addition to *gathering information*, he would collect *questions from homework*, *points earned on an assessment*, and have students complete an *item analysis for a quiz or test* with regards to the questions they answered incorrectly. By collecting *questions from homework*, George was able to focus on the questions the majority of students had, and could provided individual assistance to a student who was the only student with a question or questions (Post-observation interview, 3/28/14). Furthermore, giving students an opportunity to state which questions they needed help on allowed George to "save a lot of time in class" because he focused his efforts on those questions the majority of students needed help with instead of going over all the questions or trying to guess which questions students struggled with (Post-observation interview, 5/27/14). Zoe created *Quick Poll* questions from her class notes. This made for an easy transition to using the technology in a manner that seemed to align with her current pedagogical beliefs (Ertmer, 2005). She also mentioned time as a benefit to using the Navigator System because the *Quick Polls* could be automatically graded and she could get a sense of how her students performed in a matter of seconds (Post-observation interview, 10/31/14). No time on her part was spent grading these formative assessments. Instead, she had instant real-time data from students and could make an informed decision about how to proceed with instruction based on the results. Dan also used textbook questions to formatively assess his students during instruction. He cited the benefits of having the Navigator System automatically grade and itemize student responses for him. During a post-observation interview he stated that, “It’s nice because it’s all in one spot and it’s all together. And it’s already in the spreadsheet. You know if I was doing this by hand I would have to grade it and put it in the spreadsheet. It would be too hard to itemize problems like that if I didn’t have this software doing it for me” (Post-conference, Observation 2, 3/4/14). Dan’s process of collecting student practice documents several times at the end of class was also a creative use of the system. No other teacher used this method to formatively assess their students. As a result, it showed Dan’s push to help his students self-regulate and take ownership of their learning. As a result of observing all three teachers, they found ways to use the Navigator System beyond its intended use. George created questions that provided far greater insight to his students’ performance and Dan took advantage of the power of itemization to collect several iterations of student assessment data during instruction. The benefits of having the system available included time and the power to itemize information. Teachers want ways to be able to increase their instructional time and the technology helps to support this effort. Furthermore, teachers can gather information from all students and can use the real-time data to inform the rest of the lesson. The uses of technology displayed in all three classrooms seemed to be reflective of each teacher’s style of instruction and helped them make informed decisions with regards to the formative assessments of their students.

Feedback and Levels Provided to Students

The third key strategy of the formative assessment framework addresses feedback. Specifically, key strategy three allows the teacher to provide information back to students on how to reach the learning goals by providing feedback that moves learners forward. Lee (2012) synthesized literature on formative feedback that allowed for the development of a summary of feedback levels and their features. A summary of the three levels of feedback, *evaluative/normative*, *corrective/verification*, and *elaborative/facilitative*, are discussed next.

There were instances of level one, two, and three feedback present during the classroom observations. One category of level three feedback that was *elaborative/facilitative* was that of *re-teaching, explaining, or scaffolding*. Both George and Zoe demonstrated this level of feedback during instruction. Of the 60 instances of feedback that all three teachers provided to their students, 27/60 (45%) instances were level one, 17/60 (28.3%) were level two, and 16/60 (26.7%) were level three feedback. Although a focus on student achievement was not part of this study, the high percentage of level one feedback provided to students tends to indicate that no effect on students learning would result (Lee, 2012). With regards to key strategy three, one must question if the feedback provided to students in the form of *re-teach, explain, scaffold* did indeed move their learning forward. There were also 19 different categories of feedback that teachers provided to students, supporting the idea that teachers create a formative assessment process that tends to be unique to their teaching styles and formative assessment needs.

The process of formative assessment was unique to each teacher. This included the system features used to elicit evidence of student understanding, the questions they posed, and the feedback provided to students after reviewing the real-time data collected, displayed, and organized by the Navigator System. Although each teacher found unique ways to use the Navigator System that tended to fit well with their teaching styles, there are still refinements for all five key strategies that they could improve on that may benefit their students understanding of the mathematical content being learned. This includes assessment criteria for student performance, choosing questions that balance procedural and conceptual understanding, providing level two and three feedback more often to students, establishing collaborative group work norms and expectations, and providing students with an opportunity to reflect on their learning through self-regulation and metacognition.

A Theoretical Framework of Formative Assessment

The results of this work helped to provide baseline data on secondary mathematics teachers' formative assessment processes in classrooms that integrate TI-Nspire Navigator System into instruction. As a result of this baseline data, the need for a framework of formative assessment using this technology is suggested.

In this section, the components of a theoretical framework of formative assessment using TI-Nspire Navigator System will be shared as informed by the results of this research and existing literature on the process of formative assessment and feedback. The literature that helped to inform this framework comes from Black and Wiliam (2009), Smith and Stein (2011), and Lee (2012).

Each of the three teachers in this study demonstrated all five components of the formative assessment framework as suggested by Black and Wiliam (2009). However, what currently is lacking from the literature is the process by which each of the five key strategies is implemented during instruction. As a result of this research, we see that the process of formative assessment was unique to each teacher. However, similarities in the processes included the implementation of key strategies two and three to elicit evidence of student understanding using the Navigator System, and using the real-time data to provide feedback to students. Figure 28 is my suggested theoretical framework for formative assessment in classrooms that use the TI-Nspire Navigator System and student graphing calculators.

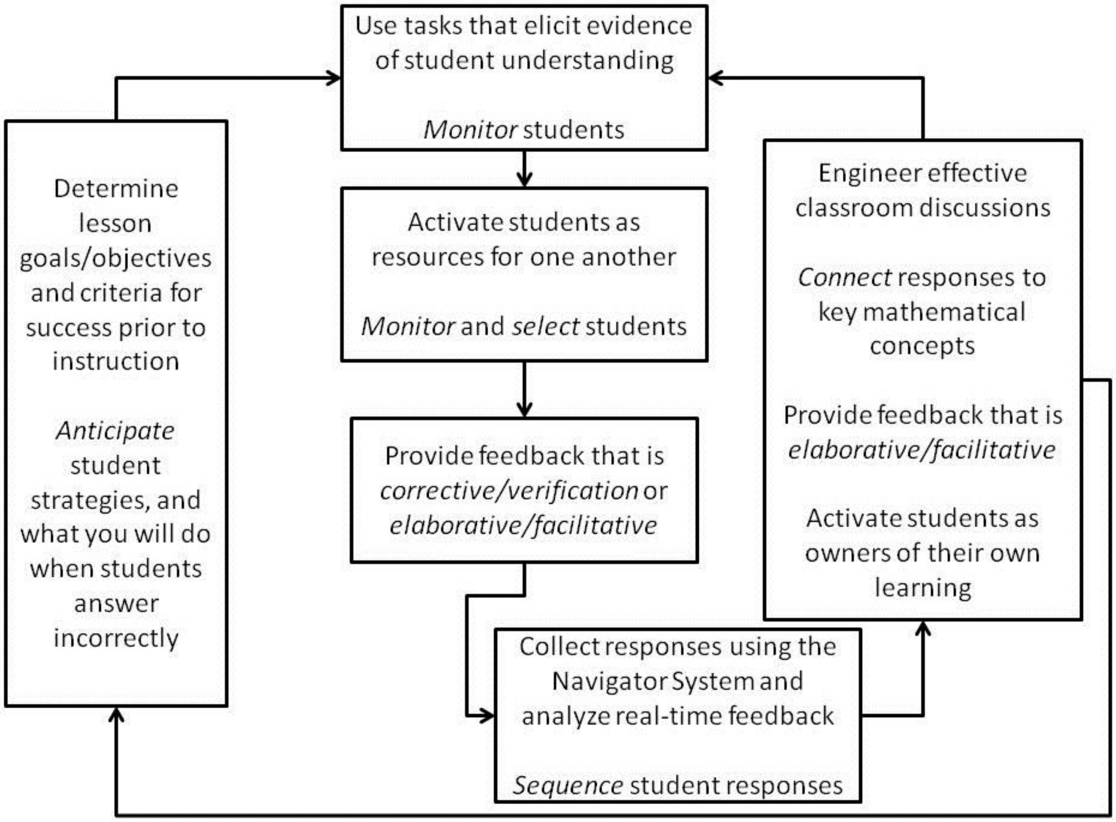


Figure 28. Theoretical Framework of Formative Assessment using Navigator System Technology.

This framework of formative assessment begins with planning prior to instruction. During planning, the teacher needs to identify the learning intentions and criteria for success. Then, the teacher should anticipate how students will respond to the questions or tasks posed during instruction and what to do when students answer incorrectly. This information then informs the tasks that students will engage with during instruction to make the learning happen. The teacher should try to pose a question at the beginning of class as a way to elicit evidence of student understanding for the given mathematics content. Then, students should be given the opportunity to think about their strategies and share their thinking with a partner using a think-pair-share method (Lyman, 1987). While students collaborate on the given task, the teacher should monitor student progress, and provide feedback that is *corrective/verification* or *elaborative/facilitative*. Then, using the Navigator System, responses from all students can be collected and the real-time data analyzed on the spot. As the teacher reviews the student responses, they can generate a sequence in which students will share out their strategies and explain their answers. The teacher should then use student responses to engage in effective classroom discussions by asking students to verify their solutions and to share their thinking. At this point in the lesson, connections between student responses and the learning goals need to be facilitated by the teacher. As students articulate their responses, they will engage with metacognition (Flavell, 1979). As time permits, this process can repeat for additional questions. Once class has ended, the results from the day's lesson and the responses students provided should be used to inform the learning goals for the next day.

Limitations

This work consisted of qualitative case studies of three secondary mathematics teachers. The goal of this research was to provide baseline data regarding secondary mathematics teachers formative assessment processes in classrooms that integrated TI-Nspire Navigator System into instruction. This study allowed for a thick description of the formative assessment processes as they occurred during instruction. However, there were limitations with respect to the participants and data collection.

The small number of participants does not allow for the results of this study to be generalized to all teachers. Since the specific population of TI-Nspire Navigator users is small, it was difficult to find teachers teaching the same subjects. Hence, the analysis consisted of teachers who used the Navigator System, but taught different subjects of mathematics at the secondary level. This also contributed to the lack of generalizability of the research results. Although there were commonalities with regards to the key strategies that appeared in each teacher's process of formative assessment, how they were implemented into instruction differed. This resulted in three unique formative assessment processes. The second limitation with regards to participation in this study dealt with the technology. By choosing the TI-Nspire Navigator System, the number of potential participants greatly diminished because this specific technology is not commonplace in all mathematics classrooms. Reasons may include cost of the system and time to learn how to use the technology during instruction. Hence, the number of potential participants was limited by the restriction of the technology.

Limitations with regards to the key strategies of formative assessment also existed. During data collection, the focus was on the actions of the teacher, not the students, as a means to gather baseline data on how the system was used during instruction and to learn about the teacher's process of formative assessment when using the technology. Hence, I was unable to provide comments regarding the impact of the questions asked of students, the feedback students received, how students collaborated in groups, and how students used the real-time data to self-regulate their learning. Furthermore, I was unable to comment on the impact of these formative assessment processes on student achievement. I could only use the framework by Lee (2012) to indicate what effect the feedback might have based on the level of feedback each teacher provided during instruction with respect to the key strategies of formative assessment. Although these limitations exist, the results of this study may be useful for further studies with respect to the formative assessment process using technology.

Implications

With respect to implications for teaching, the key strategies of formative assessment present during instruction (Black & Wiliam, 2009), the importance of feedback to move learning forward (Lee, 2012) and use of technology during instruction will be considered. Suggestions will be made based on the results of this research for additional work that needs to continue in the area of formative assessment and when using technology during the formative assessment process.

Implications for Teaching

The use of formative assessment can be more than *gathering information* from students. The affordances of the Navigator System allows a teacher to quickly gather information from students, but also provides an avenue to allow entry into conversations with students regarding their thinking based on the responses they provide through the system. Teachers will find ways to use the technology to fit their teaching styles and to meet their needs and the needs of the students in their classrooms. When using technology during the process of formative assessment, teachers need to make sure the learning intentions and criteria for success are clearly articulated to students. This includes providing information for how students will be assessed, not only what they will be assessed on. Second, teachers need to consider the types of questions they ask their students and where they fall on the procedural to conceptual continuum. They can also consider the cognitive demand of the questions (Smith & Stein, 1998). The key is to find a way to use the technology to support a balance of questions along the continuum and to alter the types of questions they ask students during instruction. Third, the feedback that teachers provide to students to move learning forward is going to be impacted by the types of questions that are asked and the goals teachers have established for the lesson. The summary of feedback levels as described by Lee (2012) provides a framework that teachers can use to help ensure the type of feedback they provide to students shifts from *evaluative/normative* with a focus on the grade towards *elaborative/facilitative* that not only identifies an error, but provides information for how to remedy the error. This is best described by the following softball analogy provided by Wiliam and Thompson (2008):

> Consider a young softball pitcher who has an earned run average of 10 (for readers who know nothing about softball, that's not good). This is the monitoring assessment. Analysis of what she is doing shows that she is trying to pitch a rising fastball (i.e., one that actually rises as it gets near the plate, due to the back-spin applied), but that this pitch is not rising, and therefore ends up as an ordinary fastball in the middle of the strike zone, which is very easy for the batter to hit. This is the diagnostic assessment, but it is of little help to the pitcher, because she already knows that her rising fastball is not rising, and that's why she is giving up a lot of runs. If a pitching coach is able to see that she is not dropping her pitching shoulder sufficiently to allow her to deliver the pitch from below the knee, then

> this assessment has the potential to be not just diagnostic, but formative. It provides the athlete with some concrete actions she can undertake in order to improve. (p. 62)

From the except above, telling the pitcher her fastball is not rising would be *evaluative/normative* feedback whereas informing the pitcher about her shoulder position in relationship to her knee is elaborative/facilitative because the coach has identified the mistake and provided information on how to correct it. Similarity, this analogy can transfer to a mathematics classroom and the feedback provided to students with regards to their progress on questions and tasks during instruction. Collaboration among students can be beneficial if students work as part of a group, not just in a group and if each student is responsible for some contribution to the work of the group (Slavin, Hurley, & Chamberlain, 2003). Finally, providing students with opportunity to reflect on their learning will help students be owners of their own learning. By familiarizing themselves with available research information on question types, feedback, collaborative work, self-regulation, and metacognition, teachers can develop formative assessment processes that will support their students understanding of mathematics.

Implications for Research

This study was conducted because of the need to identify detailed formative assessment processes of secondary mathematics teachers who used TI-Nspire Navigator System during instruction (Pape et al., 2012). Although this study did not focus on gains in student achievement, it did provide insight to three secondary mathematics teachers formative assessment processes. This baseline data then helped to inform the development of a theoretical framework of formative assessment when using the Navigator System technology. This baseline data and the theoretical framework can be used in future studies to determine the impact on student achievement. This research provided details regarding the five key strategies that appeared in the classrooms, each teacher's actual formative assessment process as implemented during instruction, the system features used, the questions asked, when questions were created, the feedback provided to students, and feedback levels. Although these results are not generalizable, they help to provide a foundation of baseline data regarding formative assessment processes of teachers who integrate technology into their classroom for future research.

There is also a need to consider the types of questions that teachers ask in classrooms with technology and how these questions differ from those in classrooms without technology. The framework of Boaler and Brodie (2004) offered a list of questions in classrooms without technology. However, the affordances of the technology offered teachers the ability to create several additional categories of questions that teachers asked their students that were not reflected in Boaler and Brodie's framework. Examples included selecting *questions from homework*, *item analysis for quiz or test*, *points earned on an assignment*, *correct text entry/computation*, and *monitoring student progress*. With technology, the possibility for additional question types emerged. This work adds to the existing teacher questions when using technology. However, there is a need to look at additional research on teacher questioning when using technology other than graphing calculators during instruction.

Conclusions

The process of formative assessment implemented by teachers who use TI-Nspire Navigator System during instruction is unique. Given the limitations inherent to qualitative case study research, the results from this work provides baseline data regarding secondary mathematics teachers' formative assessment processes in classrooms with TI-Nspire Navigator System. This information can help teachers consider their current process of formative assessment, the questions they ask, the feedback they provide students, the role of collaboration during instruction, and the opportunities they give their students to reflect on their learning. Based on these results, the proposed theoretical framework of formative assessment can be used in future research as a means to learn how the implementation of formative assessment using TI-Nspire Navigator System might lead to gains in student achievement.

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Appendix A: Initial Teacher Interview Questions

The co-investigator will ask questions like the following during the initial teacher interview:

Initial Interview 30 – 90 minutes, depending on the responses of the participant

1. Tell me a little bit about yourself.
2. Can you talk about your educational background – undergrad, major, minor, grad?
3. How many years of teaching experience do you have? (total, at this school)
4. Describe the courses you have taught. Which is your favorite and why?
5. How long have you used tech in the classroom? – when did you first start to use tech? – what influenced you to start using tech?
6. Explain how you use tech during the lesson. (How often is the tech used?) (SMART Board/Notebook, Internet, Graphing Calculators, GSP, GeoGebra, etc.) (used for supporting learning, visual representations, to transfer information, as a formative assessment tool)
7. Do you have a school wide policy for math students and technology? If so what is it? Are they required to buy graphing calculators?
8. Are students allowed to use technology on assessments (quizzes, tests) in your class?

9. Do you notice any differences in students when they use tech? (are they more engaged in the lesson, excited to use the tech to learn)
10. Do you think the tech helps them to learn the material better? Please explain.
11. Is there anything else you would like to share?

Appendix B: Classroom Observation Protocol

(adapted from http://ed.fnal.gov/trc_new/program_docs/instru/classroom_obs.pdf, http://www.netc.org/images/pdf/observation.rubric.pdf, and http://www.horizon-research.com/instruments/clas/cop.pdf)

Teacher ________________________M / F Date ______________________________
School ____________________________ Grade/Level ________________________
Time______________________________ Topic______________________________
Placement of class or lesson within the unit of study:

Copies of instructional materials to be used in lesson collected?
Describe the physical environment of this classroom:

Purpose (objectives/goals):
Intended outcomes:
Materials Used (teacher-made, manufactured, district or department-developed; characterization of materials):
Assessments (for this lesson):

Ratio of students to technological devices:

(***Fill this out as you are observing classes.***)
1 - Description of the classroom:
2 - Teaching aids/materials (per activity/task if appropriate):
3 - Assessment strategies used (per activity/task if appropriate):
4 - Time not devoted to teaching and nature of non-academic or procedural activity (e.g., management, announcements, discipline); description of non-instructional event :

In each category below, ***check as many as apply*** *during the time of the observation.*
5. Activity: _Individual _Small group _Whole class _Student Presentation _Teacher Presentation
6. The specific uses of technology in this session were
__required of all __required of some __unrestricted
7. Technologies in use: _Computer _Internet _E-mail _graphing calculator (Type)________
_One-way video _Two-way Interactive video _iPad __Navigator System (Version)______

Others:

---

8. Technology used for:
__Drill and practice
__Problem solving
__Inquiry/conjecture
__Data collection/analysis
Other:

9. Considering only the *instructional time* of the lesson (listed in 1a above), approximately what percent of this time was spent in each of the following arrangements?
a. Whole class _______ %
b. Pairs/small groups _______ %
c. Individuals _______ %

10. Based on time spent, the focus of this lesson is best described as: (Check one.)
a Almost entirely working on the development of algorithms/facts/vocabulary
b Mostly working on the development of algorithms/facts/vocabulary, but working on some concepts
c About equally working on algorithms/facts/vocabulary and working on concepts
d Mostly working on concepts, but working on some algorithms/facts/vocabulary
e Almost entirely working on concepts

11. Explain the instructional strategies used during the lesson:

12. What kinds of manipulatives were used during the lesson:

13. What technologies were used during the lesson:

14. Check here if the lesson included a major interruption (e.g., fire drill, assembly, shortened class period):

15. For Hands-On
Groups (pairs, threes, fours):
Cooperative/collaborative (yes, no):

16. Notable non-verbal behavior:

Teacher Role:
17. source of knowledge or facilitator
18. questions/comments ask for memory/fact or questions ask for comprehension/opinion
19. Understanding

Classroom Activities:
20. algorithms or heuristics
21. abstract or connected to real-world
22. prescribed program or compiled
23. closed questions or open-ended questions
24. teacher seeks facts or teacher seeks understanding
25. teacher provides reasoning or teacher seeks reason through thinking process

26. Classroom norms for using technology:

Appendix C: Pre-Observation Interview Questions

The co-investigator will ask questions like the following during the pre-observation interview.

Questions to ask prior to the class observation 15 – 30 minutes

1. Can you provide an overview of the lesson, describe what you plan to do in the lesson? (will the topic be one day/multi days)
2. Do you have any plans for collaborative work? (pairs, small groups) if yes, what will students be doing in groups?
3. Will technology be used during the lesson? If yes, please explain how the tech will be used.
4. How will the technology support student learning?
5. What do you want students to learn by using the technology?
6. How will you assess students/How will you know students learned what you want them to learn?
7. Is there anything else you would like to share about the lesson?

Appendix D: Post-Observation Interview Questions

The co-investigator will ask questions like the following during the post-observation interview.

Questions to ask after the observation 15 – 30 minutes

1. Please describe any changes to your original lesson plan.
2. Was the technology used in the manner in which you planned? If no, please explain what was different.
3. If you were to teach this lesson again would you make any changes? If so what would you do differently?
4. Please describe any changes to the use of technology you would make, if applicable.
5. How did you use technology to support the formative assessment process?
6. How did you use this information to inform instruction?
7. Is there anything else you would like to share?